The Open University

S102PRP/S510 MODULES 5/6 INTO SCIENCE

MODULES 5/6
FOOD AND DRINK: A CHEMICAL STORY

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4.1

STUDY GUIDE

Modules 5 and 6 are written and presented as a single text. If you are completely new to chemistry, the combined Modules will probably take about ten hours to study. Thus, we have allowed two weeks in the study programme for you to complete the work. You should aim to have reached the end of Section 2 by the end of the first week. However, as Section 2 is the longest and most challenging Section, do not worry if you haven't finished it by then.

Modules 5/6 introduce you to the language and the symbols used by chemists to explain the way in which atoms—the building blocks of matter—join together. In the whole Universe there are only about one hundred different kinds of atom. Yet they somehow combine together to make the myriad of different substances that we see around us. How they do this is the major part of this text. Equally important, however, is the context in which the chemical story is told: chemistry is crucially important to our health and to the well-being of our environment, and these concerns form the framework for the pair of Modules. To develop your skill of gleaning information from tables, much of the data in these Modules are presented in tabular form.

There is one very small piece of practical work. To do it, you need a plastic hair comb and a piece of thinnish paper such as newspaper or tissue paper. Although it only takes about three minutes to do, it is important and you should not leave it out. There is a new kind of exercise which involves reading and listing the contents of some items found in the home, such as packets of food.

As there are rather a lot of in-text questions (ITQs) in these Modules, a word of explanation may be useful. Many ITQs simply ask, in straightforward form, points that have been explained in the immediately preceding paragraphs. The repetition is intended to emphasize their importance and to aid your understanding.

Finally a cautionary word about the 'Explanation of terms used', which is listed in Appendix 1. Descriptions of some of the terms (printed in bold in the text) will only make proper sense when you have read most of the double Module. For example, you will meet the word 'molecule' early on in the text where it is printed in bold. Yet the explanation of 'molecule' in the Appendix includes ideas that are not introduced until much later.

1 INTRODUCTION

As humans, we obtain the essential substances we need in order to survive in three ways: through the liquid we drink, the food we eat and the air we breathe. These Modules examine some of the chemistry associated with the components of air, food production and the quality of our drinking water. The last two issues are closely related not just because we need food and water in order to exist, but also because the intensive demand for food has caused some problems with the quality of our drinking water. We also examine how some of the important environmental issues raised by these topics are dealt with in the media. As you will see, it is necessary to understand some of the basic ideas of chemistry in order to follow the debate about many environmental issues—and also to avoid being misled by unbalanced or inaccurate reporting in the media.

In this introductory Section we examine two examples of the ways in which the language of chemistry is used. The first is the fairly precise way that labelling occurs on food packaging. The second is a less precise use in a newspaper article.

1.1 FOOD LABELLING

Let's start with a simple question; what chemicals are there in food? Your kitchen is a good source of information in trying to answer this question, as many foods now have labels which give nutritional details. Breakfast cereals, dried vegetables, soups, crisps, tubs of margarine and sauces are particularly useful sources of such information.

EXERCISE 1

Make a list of the terms you can find printed on various food packets in your home under the general heading of 'nutritional information'. Note that this is different from the 'list of contents'; the latter may include other foods, flavourings and additives. Start by looking at any cereal packets and margarine tubs but you can extend it to cover other items if you wish. From a brief look through our cupboards we found the terms given in Table 1. Do not worry if these terms do not mean much to you, if you have not found all the items in Table 1 or if you have found others.

TABLE 1 List of nutritional terms found on some food packets.

Energy
Protein
Carbohydrates:
Starch(es)
Sugar e.g. glucose
Fibre
Salt (often labelled sodium chloride)
Iron
Calcium
Fats:
Polyunsaturates
Saturates
Vitamins (various)

Scientists like to classify substances according to type and then break these classes down further into subdivisions. We do much the same thing in other areas of our lives. Take, for example, the different games that people play. We classify them into ball games, board games, party games, Olympic games, mind games and so on. These classes can themselves be subdivided. The Olympic games can be divided into athletics, boxing, archery, rowing, swimming etc. We can even divide these subdivisions further—think of all the different types of activity that go to make up athletics.

By the beginning of the 1990s, chemists had named and listed some nine million different chemicals! So it is a relief that these, too, are classified into a whole variety of groups and sub-groups. None of these matters a great deal at present, though during your study of Modules 5/6 you will come to recognize some categories very well. The list in Table 1 covers several major classes of chemical substances. Some of these are discussed in more detail in these Modules—*saturates* and *polyunsaturates*, words frequently used to describe dietary fats, for example.

With the exception of 'energy' (which is a measure of what our body can do with the food as you will see in Module 7), the items listed in Table 1 are all **chemicals**. Indeed everything around us, whether beneficial or harmful to us and our environment, is made of chemicals. Without some knowledge of the chemistry of our world we cannot understand our relationship with our environment.

1.2 SCIENCE AND THE MEDIA

Over the last decade, the number of articles and programmes in the media that are linked to science has increased enormously. Concern about the environment is one factor, but there is also a tendency for us to want to know about science and how it affects the quality of our lives.

In order to examine the portrayal of science in the media, we could have looked at one of the more sensational articles that might appear in the tabloid press or a more serious article from one of the 'quality' dailies where science-based issues abound. An article that deals with the quality of drinking water in eastern England is printed below. Though specifically written for these Modules, the Article is typical of the kind of report that appears in serious newspapers.

What we do in these pages is to see how the information in the Article has been presented and, in the light of the science that is developed in Modules 5/6, to see whether the story should have been told in a different way. By the end of these

Modules, you will be able to look at the Article critically—as a scientist—and re-assess the information given.

Quickly scan through the Article. There will probably be a number of terms and ideas with which you are not familiar, but all you need to do at this stage is to get some idea of what the Article is about and what its main message appears to be.

□ What does the main message of the Article appear to be?

■ The Article suggests that it is dangerous for children under the age of 12 months to drink tap water in the eastern counties of England.

But is this truly the case? Can it *really* be that water companies are supplying drinking water that is a health hazard? Will you ever trust the kitchen tap again? Possibly, however, the fault lies with the Article rather than the water. What is written there may be wrong or misleading. Only by developing a sufficient knowledge of chemistry will you be able to make a proper judgement. Meanwhile, we can at least look very carefully at this Article to explore the information on which it is based.

EXERCISE 2

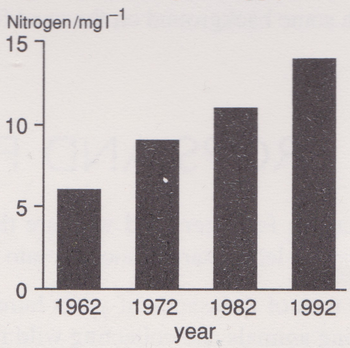
One way to do this is to identify the various words and phrases of uncertain meaning—things about which you need more knowledge in order to understand fully what the Article is saying. For example, *what are nitrates* and *why do plants need them?* So, read the Article again and identify words and phrases where more knowledge is required. (To do this use a highlighting pen, underline

Water threat to babies' health

From our Environment Correspondent

A REPORT published today indicated that water supplied to homes in East Anglia may pose a health risk to babies. Levels of nitrate, which have been rising for several years, at times exceeded the safe levels for drinking water in 1991. The maximum level recommended by the World Health Organization (WHO) for nitrogen is 10 milligrams per litre. This level was breached on no less than twenty occasions during the year in the counties of Norfolk, Suffolk and Essex. (The allowed level for nitrate in the EC is about five times higher.) Much of the drinking water for this region comes from underground sources and levels have been significantly depleted over the last few years of below average rainfall. This means that contaminants will have an increasing effect as the concentration in a smaller amount of water will increase and that is just what has been happening. The chart shows changes in the past 30 years.

Nitrate is a major component of the fertilizer used on the farms of East Anglia. Some is absorbed by crops where it is used to build up proteins but the larger proportion is either washed into rivers and lakes by rain or percolates downwards to contaminate the water table. Nitrate fertilizer is relatively inexpensive and is often applied liberally to ensure that crops have an adequate supply.



Ground water impurities

At current levels it seems unlikely that nitrate will harm adults who consume a modest amount of water each day.

The big danger is to babies up to the age of twelve months. Nitrate can limit the ability of blood to carry oxygen to the growing tissues of a young baby. A characteristic feature of the condition, which can prove fatal without medical treatment, is the development of a blue pallor to the skin. 'Blue baby syndrome', once a very rare condition, has seen a small but significant rise in cases over the last ten years.

Removal of nitrate can be achieved but it is expensive in terms of the cost of the equipment to handle the large volumes of water involved and in running costs. The alternative approach of limiting the amount of nitrate fertilizer used on the land will mean a cost in terms of reduced crop yields. This is already happening particularly in designated Environmentally Sensitive Areas (ESAs). These, and related questions, will provide the focus of discussion at the next meeting of the Environmental Policy Unit.

NEWSPAPER ARTICLE 'Water threat to babies' health'.

words or make marginal notes.) Now compare your set with those listed in Table 2.

TABLE 2 List of terms where more knowledge and understanding is required.

Nitrate	On what criteria are recommended nitrate levels based?
Nitrogen	Water table
Oxygen	Blue baby syndrome
Fertilizer	How do nitrates limit the ability of blood to carry oxygen?
Proteins	Why are nitrates more of a problem for babies?
Why do plants need nitrate?	Concentration

Our list is quite extensive and you may not have come up with all the words and phrases. If you have a few items, then you are off to a good start. You have demonstrated to yourself that to judge an argument you need to understand the terms used in it.

As you selected your items, you may have already found yourself being suspicious of some of the arguments in the Article: perhaps because the reasoning was unclear or because some of the deductions seemed unjustified. The author of the Article may have been selective with the facts or have given insufficient information to back up the arguments or conclusions. The following lists some of the questions that might occur to a critical reader:

What is the difference between ground water and drinking water?

Do the terms 'nitrogen' and 'nitrate' have the same meaning and, therefore, are 'nitrate level' and 'nitrogen level' the same thing?

Why does there appear to be different allowed levels of contaminants in water in the EC compared with those recommended by the World Health Organization?

In the next Section we stand back from the Article to explore some of the underlying chemistry, so that we can re-assess the information given. As we make this chemical journey, here and there references back to the Article will be made—watch out in particular, for references to nitrogen and nitrate—but not until Sections 5 and 6 will we return to the Article and re-examine it in the light of our new knowledge.

For now, to put chemistry into the context of the every-day world, let's begin with some background on the need for and the use of fertilizers in crop growing.

2 CROPS AND FERTILIZERS

What are fertilizers and why are they used on crops? In order to answer this question, let us start by looking into the past.

For tens of thousands of years humans were nomadic hunters and gatherers—killing animals and collecting wild fruits, roots and seeds for their food. As trees were harvested, plants eaten, and the herds of animals moved around, so the people moved on. For the comparatively small populations that lived then, there was an abundance of food.

Around 10 000 years ago, most of the small hordes of wandering people began to settle in their own patches of territory. There were insufficient wild plants in any one spot, and passing herds could not be relied upon—and so agriculture and animal husbandry began. Trees were felled, the land was cleared and wild

seeds became the crop seeds that were sown in the new patches called fields. In some of the fields, captive animals were kept for their milk, meat, hair and skins. Food supply became much more predictable: after a spring sowing, there was always—well, almost always—an autumn of plenty.

The fact that crops could be harvested over and over again from the same piece of land seems, at first sight, to be quite remarkable. It really does look as though people obtained their crops and nourishment from the land without anything being put back into it. That is, of course, not so. Until recent times the farmers allowed the land to be sustained naturally. When crops were harvested, much of the plant was left in the soil. Grains were cut so that just the heads were removed—and the remaining parts of the plants were left to rot down on the land after the edible parts had been harvested. Moreover, there was a careful rotation of the crops to make the best of the soil, and a careful use of the excrement of the animals to enrich the land.

But, in the last century or so, populations began to soar. Ever greater yields were demanded from the same area of land to feed the burgeoning populations. Traditional methods of ensuring that the soil had sufficient nutrients were not enough—and the era of artificial nutrients, of chemical fertilizers, had come. And with it came problems.

But what *are* fertilizers? What substances do plants need in order to grow? Of what substances are plants made? Similarly in the case of animals that feed on the plants: the same question can be asked, 'Of what substances are they made?' For 'substances' read 'chemicals': *everything* around us is a chemical. The next Section examines these questions a little further.

2.1 WHAT ARE PLANTS MADE OF?

If you peel off the outside of an onion, you find it is made up of layers. It is possible to take a thin sliver from one of these layers and look at it under a microscope. What you might see is schematically illustrated in Figure 1.

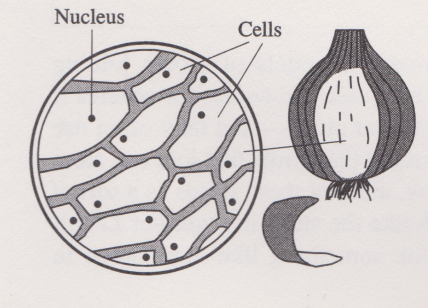


FIGURE 1 A view of a sliver of onion, as seen under a microscope—magnified about 100 times.

The individual objects that you see are **cells**, each of which contains a small round object called the **cell nucleus**. Cells are small structures that, when put together, form the whole of the onion. They are the sites where much of the working of the plant takes place. The onion uses its food to grow and the cells are tiny chemical factories where food is turned into materials that the onion needs.

Humans are also made up of cells. If you compare the onion with your own skin, you may think that there is little similarity. But if you magnify human skin as shown in Figure 2, and compare it with Figure 1, you may think differently.

□ What similarities and differences can you see in the diagrams of the onion and skin cells?

■ All cells in both Figures contain a cell nucleus. The onion cells are more rectangular in shape than the skin cells which are round. The onion cells have thick walls on the outside of the cell.

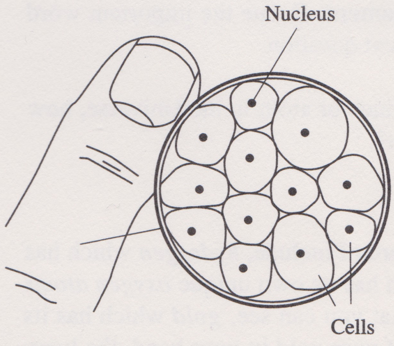


FIGURE 2 A view of a piece of human skin, as seen under a microscope—magnified about 100 times.

Cells in the skin have the same purpose as they do in the onion. They are the units, the factories, that carry out important functions. They are also composed of similar substances to those found in onion cells—which explains their broadly similar appearance.

If we increased the magnification of the onion cells to 1 000 000 000 times, we would see a very different picture from that depicted in Figure 1. Perhaps more remarkable is that a similarly magnified view of the human skin would appear to be almost identical to that of the onion. At this magnification **atoms**—the building blocks of matter—would be visible. You first met atoms in Module 4.

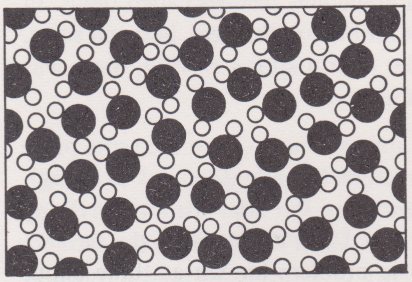


FIGURE 3 The individual atoms in water that could be seen if the drop was magnified 10^9 times. The white circles represent hydrogen atoms, and the black ones represent oxygen atoms.

There you learned that they are very, very small—around 10^{-10} m in diameter. Because they are so small, some kind of *model* is needed to represent them and, moreover, to show how they are linked together.

Figure 3, a reproduction of Figure 8 of Module 4, shows how two hydrogen atoms (small white circles) are joined to one oxygen atom (larger black circles) to form each particle of water. The proper term for each 'particle' of water is **molecule**. Practise these new terms with this in-text question.

☐ How many hydrogen atoms and how many oxygen atoms are there in one molecule of water?

■ Two hydrogen atoms are joined to one oxygen atom to make one molecule of water.

Remembering that scientists use the term 'model' to mean any written-down method of representing some structure or idea, you won't be surprised to realise that there is more than one way of making a model of a water molecule. Figure 3 is one version, but there are others. If you are familiar with the children's toy called *Lego* or its more junior version called *Duplo*, you may find that a model based on these is helpful: see the Box below.

> USING *LEGO* OR *DUPLO* AS A MODEL FOR A WATER MOLECULE
>
> In this kind of building set, there are a limited number of types of block and each block has a particular shape. Just as importantly, each one has a particular way in which it can link to other blocks because of the way the studs are arranged.
>
> The blocks can help us see how the atoms link in a molecule of water. Look at Figure 4 where the black brick represents an oxygen atom and the white bricks represent hydrogen atoms. There are only two locations where the hydrogen atoms can join the oxygen atom—at the top and bottom—as shown in Figure 4.

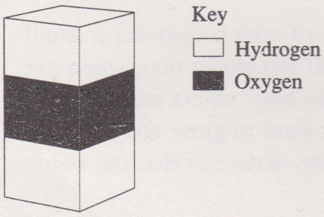


FIGURE 4 *Lego* representation of water.

Chemists have their own convention for making models of atoms joining together to make molecules. As in Figure 3, they often use circles (or spheres if they make a three dimensional model) to represent atoms—and they often use *short straight lines* between the circles to represent the **bonds** that join one atom to another in molecules such as water. For now, think of these bonds as a sort of 'cement' that holds the atoms together (much like the studs in *Duplo* or *Lego*). Thus a chemist's picture of water might look something like that shown in Figure 5.

With *Lego*, it is possible to build an enormous range of structures from a small number of different types of block. It is just the same for atoms: recall from the Study Guide that, in the entire Universe, there are only about one hundred different types of atom! Yet everything around us is built from these atoms.

Each different type of atom is known as an **element**. Relate the important word 'element' to the term 'atom' by doing this in-text question.

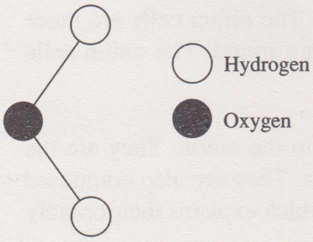


FIGURE 5 A chemist's representation of water. Note: although the hydrogen and oxygen atoms are shown as the same size, they are in fact different sizes.

☐ If there are about one hundred different kinds of atom in the Universe, how many kinds of elements do you think exist?

■ About one hundred!

Examples of elements that you might have heard of include, *hydrogen* which has its own unique *hydrogen atoms*, *oxygen* which has its own unique *oxygen atoms* and, if you want an example of an element that you can see, *gold* which has its own unique *gold atoms*. If you hold a piece of pure gold in your hand, the lump of yellow metal contains nothing but identical atoms of the element gold.

TABLE 3 The ten most common elements in the human body and the approximate percentages of each (of the total number of atoms in the body).

Element	%
hydrogen	63.0
oxygen	25.2
carbon	9.5
nitrogen	1.4
calcium	0.31
phosphorus	0.22
potassium	0.06
sulphur	0.05
chlorine	0.03
sodium	0.03
All others	0.20

Table 3 gives the ten most common elements in the human body which together make up 99.80% of the total number of atoms present in the body. One important kind of atom in living systems, the third one down in Table 3, is that of the element *carbon*. It is possible to have some of the element itself—that is some pure carbon containing nothing but carbon atoms—pick up a piece of charcoal of the type used in barbecues, for example, and you've got some.

Let's apply the idea that atoms are very small to a piece of charcoal and see how many atoms are in it. Start with a piece about the size that would fit comfortably into a teaspoon, this would be about 12 grams of carbon. How many times could we divide this before we arrived at a single carbon atom? Take a knife and cut it evenly into two—to give two bits each of 6 grams. A further division of one of the pieces would give two pieces, each with a mass of three grams. Keep going!

A further seven divisions (making a total of nine in all) would result in pieces of carbon each with a mass of about 0.02 g. These are the size of crumbs, and at this stage the cutting process would become quite difficult. Each division into two, produces ever tinier pieces. But at last, after about a further *seventy* divisions, you finally get there—your last cut gives you two solitary, separate, carbon atoms. Clearly, this would be an impossible operation to perform by hand. In 12 g of carbon, there are about six hundred thousand million million million atoms or 6×10^{23} atoms, or written out as a number, 600 000 000 000 000 000 000 000. It is difficult to comprehend numbers of this scale but, if *everyone* on the planet were to count these atoms at the rate of one atom per second, it would take over 2 million years to complete the task of counting 6×10^{23} atoms, the number of atoms in the original piece of carbon.

SAQ 1

(a) 6×10^{23} hydrogen atoms have a mass of 1 gram. Calculate the mass of a single hydrogen atom in grams. (Give your answer to 3 significant figures.)

(b) 6×10^{23} carbon atoms have a mass of 12 grams. Calculate the mass of a single carbon atom in grams. (Give your answer to 3 significant figures.)

(c) Divide your answer to part (b) by your answer to part (a). By doing this you will find out how many times the carbon atom is heavier than the hydrogen atom. What value do you get? (Give your answer to 2 significant figures.)

2.2 WHAT ARE COMPOUNDS?

Although there are about one hundred elements, there are many, many more than a mere hundred substances in the world—not just thousands but millions of different substances. You could begin a list starting once again in your kitchen: water, salt, sugar, vinegar, bicarbonate of soda and so on. If these substances aren't elements, what are they? They are substances in which atoms of *different* elements are joined together. The proper chemical term for any such substance is **chemical compound** or just **compound**. Practise this term by doing this in-text question.

☐ Is water a compound or an element? Explain your answer.

■ Water is a compound. It contains more than one element: hydrogen and oxygen atoms are joined together.

An important feature of compounds is that they are very different from the elements from which they are made. For example, water is very different from the elements from which it is formed: hydrogen and oxygen are both colourless gases whereas water is the wet, liquid stuff we drink and which makes up 80–90% of our bodies. So, it is important to realise that a water molecule is quite different from the two types of atoms from which it is formed. Water is not simply a *mixture* of hydrogen and oxygen, it contains hydrogen and oxygen

atoms linked together in an ordered way. (You can make a truck from *Lego* blocks but it is unlikely that you would look at a pile of the separate blocks and say that is a truck! In scientific terminology, the truck is the molecule and the blocks from which it is built are the atoms.)

□ Look back at Table 3. From what you know about the composition of living organisms—picture a squashed tomato or squashed slug—why do you think the percentages of hydrogen atoms and of oxygen atoms are so great?

■ If 80-90% of our bodies is water, then we would expect to have a high percentage of the elements that make up water (hydrogen and oxygen) in our bodies.

The next most common element in our bodies, after hydrogen and oxygen, is carbon. This, when linked to other atoms, forms most of the compounds of which plants and animals are made (apart, that is, from water). One very important category of compounds found in plants and animals are the **proteins** (listed in both Tables 1 and 2). Part of a protein molecule is shown in Figure 6. This large molecule is made up of *only* four different types of atom; notice the complex way they are put together.

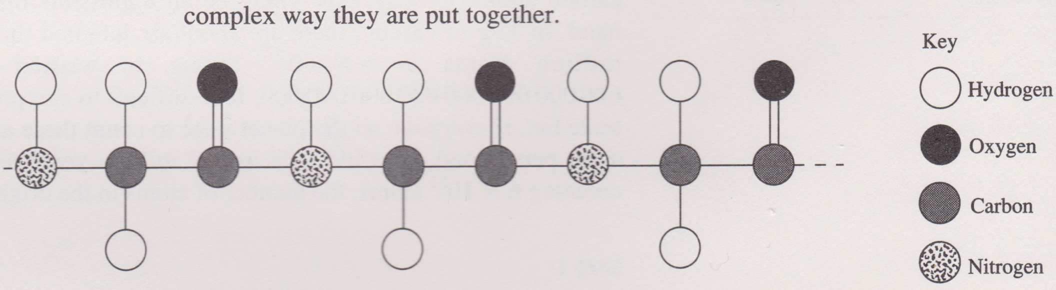


FIGURE 6 Part of the structure of a molecule of a protein. It is composed of four different types of atom.

□ Using the key in Figure 6, name the different kinds of atom (hence different kinds of element) found in a protein molecule.

■ Carbon, nitrogen, oxygen and hydrogen atoms.

Recall that nitrogen is central to the discussion in the Article. While we will not look further into nitrogen for the present, it is important that you remember that it is an element, and that nitrogen atoms are involved in the structure of a class of very important compounds, called proteins.

SAQ 2 Which of the following are elements and which are compounds: hydrogen, water, nitrogen, carbon, protein?

SAQ 3 The gas methane is a major constituent of North Sea gas. The only kinds of atoms present in a molecule of methane are those of hydrogen and carbon. Use your understanding of Sections 2.1 and 2.2 to fill in the blanks in the following correct statement.

Methane contains the … carbon and … . Methane is not an element. It is a chemical … .

SAQ 4 The atmosphere contains several different kinds of gas. About 80% of it is the gas nitrogen and about 20% is the gas oxygen. There is a small amount of other gases, one of which is carbon dioxide. From the information given in statements (a) to (c), decide whether the gas named is an element *or* a compound.

(a) The only kinds of atoms found in a cylinder of pure oxygen are oxygen atoms.

(b) In nitrogen gas, nitrogen atoms are linked together in pairs.

(c) The bubbles of gas produced in home wine making are pure carbon dioxide. Analysis shows that the bubbles contain molecules in which there are two kinds of atom bonded together, namely those of carbon and oxygen.

2.3 INSIDE THE ATOM

Before we go on to see how atoms are able to link with each other, we need to look at atoms in a little more detail. Doubtless they are not like blocks of *Lego* or *Duplo*! So what are they like?

In fact, every atom has a complex internal structure. Given the extremely small size of an atom, you may find it difficult to visualize any smaller bits inside it. However, you may already be familiar with some of the effects of one of these bits—that is, the components of the atom that are called **electrons**. It is easy to do an experiment that illustrates the presence of electrons and, moreover, shows one of their important characteristics.

EXPERIMENT 1

The items you need for this small experiment are: a plastic comb (or plastic ruler) and a small piece of tissue paper or newspaper.

Tear the piece of tissue paper or newspaper into bits about 1 cm square and leave them in a pile on a table. Rub the comb up and down several times on your clothes. (Some materials are better than others for doing this; wool and nylon are particularly good.) Now move the comb up to the paper and note what happens.

You should find that the paper is attracted to the comb. The explanation for this phenomenon is that the rubbing action transfers large numbers of the tiny electrons *from* the atoms of your clothes *onto* the plastic comb or vice versa. The plastic builds up *electricity* that attracts the paper because the electrons have an electrical *charge*. Let's look at the electrons in more detail.

Each electron carries a minute but standard amount of *negative charge*. Conventionally chemists and physicists speak of an electron as having a charge of −1. The units do not matter in this case as the '−1' is just a comparative amount: one electron has a charge of −1, two electrons a charge of −2 and ten electrons have a charge of −10.

Most objects—combs, people or atoms—do *not* usually have any net charge at all. They are described as electrically neutral. This is not a very hard concept to accept in light of some intuitive ideas from mathematics or, indeed, bank balances! Something can be negative, positive or at value zero. This value of zero means no charge at all.

□ Atoms are neutral particles; that is, they carry no net charge. If an atom can be shown to contain negative particles (that is, electrons), what else *must* there be in an atom?

■ There must be some particles carrying a positive charge to balance the negative charge of the electrons. Moreover, the total negative charge of the electrons must just be balanced by the total positive charge in these positive particles, so that the whole atom has a net charge of zero.

These positive particles are known as **protons** and each one carries the same amount of charge as an electron but has the opposite sign, +1.

□ What is the relationship between the number of protons in an atom and the number of electrons in the same atom?

■ Since they have the same charge, but opposite signs, there must be the same number of protons as electrons.

TABLE 4 The numbers of electrons and protons in five elements.

Element	Number of electrons	Number of protons
hydrogen	1	1
helium	2	2
carbon	6	6
nitrogen	7	7
oxygen	8	8

Let's look at a few atoms to put this important idea into perspective. The simplest element possible is hydrogen. It has just *one* proton and *one* electron. As +1 and −1 together give a charge of 0, it follows that the atom is neutral. Next comes helium, the light but non-flammable gas that nowadays is used to fill balloons at fair-grounds. Each helium atom has within it two protons and two electrons: together, +2 and −2 equal 0. Table 4 summarizes this and gives three more examples of elements that you have already met.

You might note, in passing, two points:

(1) Atoms with 3, 4 and 5 protons have been omitted from Table 4 for simplicity: they do exist! Indeed, the *one hundred different elements* contain atoms with, progressively, 1 up to 100 protons.

(2) Most atoms also contain electrically neutral particles called *neutrons*. These do not affect the chemistry of elements and are not discussed further in *Into Science*. They are mentioned here in case you already have heard of them and wonder about their omission.

It is the number of protons that determines the identity of each element. Thus, if an atom has six protons it *must* be an atom of the element carbon. If it has seven protons it *must* be nitrogen and so on. As the number of protons increases so the mass of the atom increases. The number of protons in an atom also determines the number of electrons in that atom and it is through these protons and electrons that the atom has its unique characteristics. Note that electrons have very little mass compared with protons.

> Each element has a characteristic number of protons e.g. hydrogen has 1.
>
> In a neutral atom, the number of protons equals the number of electrons.

Chemists picture the atom as being made up of a central **atomic nucleus**, which contains the protons, with electrons moving around it. The electrons are arranged in layers, somewhat like the layers in an onion. A simple representation of this for the element carbon is shown in Figure 7. Consult Table 4 and, using the information in the last few paragraphs, do the following ITQ. Then label Figure 7 by writing the appropriate charge by each black dot and inside the central white circle.

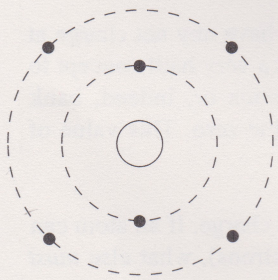


FIGURE 7 Chemists' simple representation of the carbon atom. The dots represent electrons in layers around the central nucleus shown by a white circle.

□ How many electrons and protons are there in each carbon atom?

■ There are six of each. Thus the 6 plus charges on the nucleus are balanced by the 6 negatively charged electrons. (A completed figure is given in Figure 29, Appendix 2.)

The paragraphs above describe the nature of atoms. The intriguing fact, however, is that in nature very few atoms ever exist entirely on their own. One way or another, most atoms are found joined to other atoms by some kind of bonding. There are two ways in which this bonding together of atoms can occur. Both ways depend on *'interactions' between the outermost layer of electrons* of each of the atoms that are doing the bonding.

The names of the types of bonding are fairly straightforward. One kind is called **covalent bonding** (pronounced co-vay-lent) and the other is called **ionic bonding** (pronounced eye-on-ic). They are discussed in Sections 2.4 and 2.6 respectively.

> There are two kinds of bonds between atoms: covalent and ionic.

SAQ 5 The nucleus of each atom of the element gold contains 79 protons. How many electrons are there moving around each atomic nucleus in this element?

SAQ 6 Totally dry air, from which all carbon dioxide has been removed, contains the following gases—in decreasing order of concentration.

Nitrogen (7), oxygen (8), argon (18), neon (10), helium (2), krypton (36) and xenon (54). [Note: krypton is pronounced krip-ton, and xenon is pronounced zen-on.]

All these gases are elements. The figure in brackets after each is the number of electrons in each kind of atom. How many protons are there in the nucleus of each kind of atom? How were you able to deduce these values?

2.4 WHAT ARE MOLECULES?

Covalent bonding is one kind of linking that joins atoms together. The group of atoms held together by covalent bonds is *a molecule*. The example you are most familiar with is the compound water: water consists of covalent molecules. Recall what is in molecules of water from Section 2.1.

□ What atoms are in a water molecule and how are they bonded together?

■ Two hydrogen atoms and one oxygen atom are in one water molecule and they are bonded covalently. (Look back at Figure 5.)

You have met three other compounds in the text so far: protein (Figure 6), methane (SAQ 3) and carbon dioxide (SAQ 4). These all involve covalent bonding and all exist as molecules. You have also met some gaseous *elements* that exist as covalent molecules. The oxygen gas in the air does not exist in the form of free individual oxygen atoms, but as *pairs* of oxygen atoms joined together by covalent bonds to give oxygen molecules. The same applies to the nitrogen of the air: here two nitrogen atoms join together to form a covalent molecule. (As noted earlier, elements that exist as *free, solitary atoms* are quite rare.)

Before going on make sure that you are clear about three crucial points concerning molecules, listed in the Box, and about which it is easy to make mistakes.

MOLECULES

(1) It is possible to have molecules that are elements (e.g. a molecule of oxygen) and molecules that are compounds (e.g. a molecule of water).

(2) Molecules always consist of two or more atoms bonded together (examples: two oxygen atoms bond together to make an oxygen molecule; two hydrogen atoms and one oxygen atom bond together to make a water molecule).

(3) The kind of bonding in molecules is *always* covalent. If a compound or an element exists as *molecules*, the bonding *has to be* covalent.

Let's now look at the number of covalent bonds that different atoms like to form.

□ The element nitrogen exists as a covalent molecule. From what you have read in recent paragraphs, what is in a molecule of nitrogen?

■ Two nitrogen atoms joined together covalently.

□ Nitrogen molecules and methane molecules are both covalent but one is an element and the other is a compound. Why is one described as an element and one as a compound?

■ Only one kind of atom is involved in the nitrogen molecule: nitrogen atoms. Two kinds of atoms are involved in a methane molecule: carbon and hydrogen.

Look back at Figure 6 on page 8. This is just *part* of a molecule of a protein. Recall that there are just four kinds of atom involved in a molecule of a protein: carbon, nitrogen, oxygen and hydrogen. The black lines in Figure 6 represent the covalent bonds. A protein molecule is always very large indeed, and the dotted lines represent covalent bonds going to parts of the molecule not shown in the diagram. This may look very complex, but atoms obey fairly strict rules as to how they interconnect with other atoms. In particular, there is almost always a set *number* of covalent bonds that a given atom can form.

In the rest of this Section we use models of some of the commoner atoms to show how more complex molecules, such as the protein in Figure 6, can be built up from simple atoms. This will show you how many different kinds of molecules can be built up from the same set of atoms; in short, from the chemists' *Lego* set!

Let's start by looking at the simplest atom. We have already seen that this is hydrogen and that it has one proton and one electron. Hydrogen likes to form just *one* bond with another atom. Visualizing the bonding between atoms can be very difficult—unless, once again, we make use of a model. This time we will use sketches of the different atoms somewhat similar to those used in the protein molecule in Figure 6, except that instead of straight lines we will use *hooks*. Thus, we might represent hydrogen as a sphere with one hook since it has one bond, as shown in Figure 8.

When linking atoms together to make molecules, the 'golden rule' is that no atom must ever have any spare hooks. A hydrogen atom all by itself has got a spare hook and that is *not* allowed!

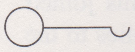
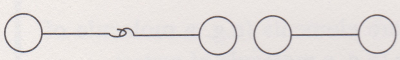


FIGURE 8 A representation of the hydrogen atom.

□ What is the simplest molecule that hydrogen atoms alone can form? Use representations of the hydrogen atom, such as that given in Figure 8, to sketch the molecule.

■ Hydrogen only forms one link with one other hydrogen atom as shown in Figure 9a.



(a) (b)

FIGURE 9 Two representations of the hydrogen molecule (a) using hooks, (b) using bonds (with the two hooks combined to form one bond).

Chemists usually draw the links between the different atoms that form molecules in the form of straight lines. This is shown for hydrogen in Figure 9b. By comparing 9a and 9b, you can see that 'two linked hooks' equals 'one covalent bond'.

Now consider something slightly more complicated than a hydrogen molecule. Methane, which is used in domestic heating and cooking, is a covalent compound that has been mentioned several times before. A molecule of methane contains only carbon and hydrogen. In fact, the molecule contains just one atom of carbon. Carbon atoms have four hooks as shown in Figure 10.

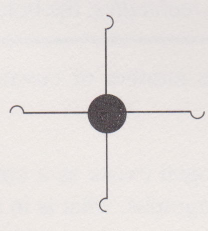


FIGURE 10 Representation of the carbon atom.

□ Use the model atoms of hydrogen (Figure 8) and carbon (Figure 10) to obtain a representation of the methane molecule. How many hydrogen atoms can be attached to the one carbon atom?

■ Your model should look similar to Figure 11a. Each of the four carbon hooks attaches to a hydrogen hook to produce a methane molecule in which four hydrogen atoms form bonds to one carbon atom. Figure 11b shows the same molecule using bonds; as before two joined hooks equals one covalent bond.

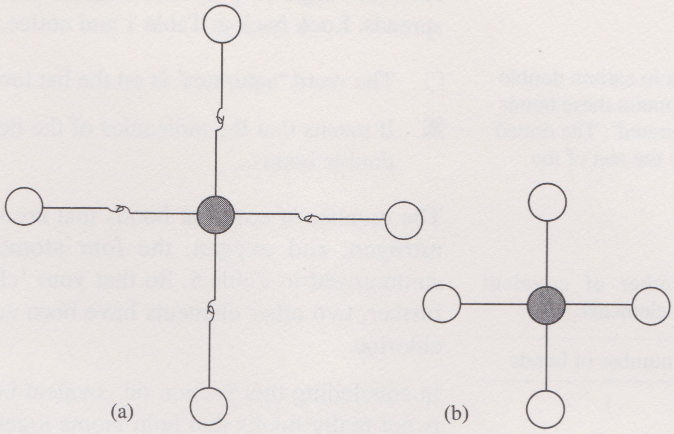


FIGURE 11 Models of the molecule methane (a) using hooks, (b) using bonds.

Now apply the model building idea to a molecule of water. Oxygen has two hooks as shown in Figure 12.

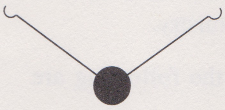


FIGURE 12 Representation of the oxygen atom.

□ Sketch a representation of the water molecule, but this time leave out the 'joined hooks' stage and write down the straight lines of the covalent bonds straight away.

■ Your answer should look similar to that shown in Figure 13.

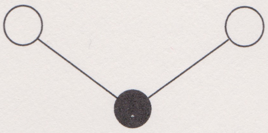


FIGURE 13 Representation of the water molecule.

Try another example: carbon dioxide. This is the molecule produced when carbon (in coal, wood or oil) is burnt and when humans or animals breathe out. The name of a compound can sometimes give useful information. In this instance the *di* in front of the oxide of *di*oxide tells us that the molecule has *two* oxygen atoms. The carbon dioxide molecule demonstrates another feature of bonding between atoms.

□ How many bonds does carbon form? Look back at Figure 10 if necessary.

■ Carbon forms four bonds.

□ How many bonds can oxygen form? Look back at Figure 12 if necessary.

■ Oxygen forms two bonds.

So, how does one carbon atom bond to two oxygen atoms in this instance? Imagine that all the hooks sticking out of the spheres of the atoms of carbon and oxygen are flexible. Try to fix them together so there are no unsatisfied hooks. The only way for all the carbon hooks to be used is (i) for *the two hooks* of one oxygen atom to link to *two of the four hooks* of the carbon atom and (ii) the second oxygen atom to link in the same way to the remaining two hooks of the carbon atom. The molecule is represented in Figure 14a.

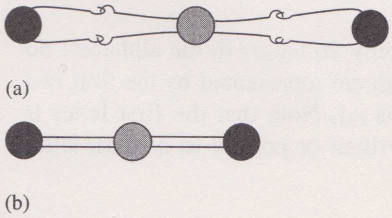


FIGURE 14 A carbon dioxide molecule (a) using hooks, (b) using bonds.

This type of sketch is quite clumsy and chemists prefer to represent the bonds as shown in Figure 14b. When atoms bond in the way shown in this Figure, the bonds formed are referred to as **double bonds** as opposed to **single bonds** such as those formed in the methane and water molecules. Look back at Figure 6—part of a protein molecule. The vertical 'double lines' you can see between carbon atoms and the oxygen atoms are carbon to oxygen double bonds.

It is entirely possible to have other molecules where carbon atoms are joined to carbon atoms by double bonds—as shown in Figure 15. Chemists have a special

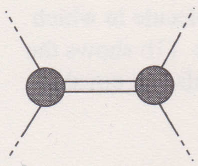


FIGURE 15 A carbon to carbon double bond. Molecules that contain these bonds are described as 'unsaturated'. The dotted lines represent bonds to the rest of the molecule.

TABLE 5 Usual number of covalent bonds formed by some elements.

Element	Usual number of bonds
hydrogen	1
carbon	4
nitrogen	3
oxygen	2
sulphur	2
chlorine	1

name for compounds that contain 'carbon to carbon double bonds'. They are described as *unsaturated* compounds or sometimes as *unsaturates*. If there are several such double bonds in a molecule they are often called *polyunsaturates*, where 'poly' simply means 'many'. You may have heard the term in expressions such as 'high in polyunsaturates' used to describe certain margarines and spreads. Look back at Table 1 and notice that 'polyunsaturates' is on the list.

□ The word 'saturates' is on the list too. What do you think that means?

■ It means that the molecules of the item of food contain *no* carbon to carbon double bonds.

The number of covalent bonds that are normally formed by hydrogen, carbon, nitrogen, and oxygen, the four atoms found in molecules of protein are summarized in Table 5. So that your 'chemistry *Lego* set' is extended that bit further, two other elements have been added to the Table, namely sulphur and chlorine.

In concluding this Section on covalent bonds it is important to remember that it is not really hooks that hold atoms together! You learnt from Figure 7 that the nucleus of every atom is surrounded by electrons. When two atoms link covalently some of these electrons are *shared* between them. This idea of 'electron sharing' in covalent bonds is an important one in chemistry.

SAQ 7 Use the information in Table 5 to decide which of the following are likely to exist as covalent molecules.

(a) One sulphur atom and two hydrogen atoms.

(b One nitrogen atom and three hydrogen atoms.

(c) One carbon atom and five chlorine atoms.

2.5 CHEMICAL LANGUAGE

The above Sections included a lot of terms which may have been unfamiliar to you; atom, element, compound, molecule and bond, for example. Chemistry has a language all of its own and coming to grips with the terminology can be as much of a problem as understanding the chemistry itself. In this Section we consider the language of chemistry before returning to our examination of bonding.

So far atoms have been represented as labelled spheres or circles and the bonds that link atoms in molecules have been represented as lines. This is a rather cumbersome method of writing down molecules. Chemists have developed their own shorthand language for the names of the elements. It involves giving each element a **symbol** consisting of one or two letters. You can guess some of them, because they start with the *first letter* of the element's name. Thus oxygen is designated by the capital letter O and nitrogen by N.

□ The symbols of the following elements are all formed in this way: hydrogen, carbon, phosphorus, boron, and sulphur. Write down their symbols.

■ The chemical symbols are: H for hydrogen, C for carbon, P for phosphorus, B for boron, S for sulphur.

However, there are about 100 elements and only 26 letters in the alphabet! So some elements such as calcium and aluminium are represented by the *first two letters*. Thus calcium is Ca and aluminium is Al. Note that the first letter is always a capital and the second is always written or printed as a small letter (lower case).

□ The symbols of the following elements are all of the type just described: helium, nickel, bromine and silicon. Write down their symbols.

■ The chemical symbols are: He for helium, Ni for nickel, Br for bromine and Si for silicon.

This may seem perfectly straightforward but for historical reasons some elements have unusual symbols. Sulphur had taken the symbol S and so an alternative was required for sodium. In fact, the symbol Na was chosen from the Arabic *Natron* (which is a salt lake in Egypt). Potassium derives its name from wood-ash, which is a readily available form of the compound potassium carbonate. The Arabic name for the process of making wood-ash is *Kali*—hence the symbol K for potassium.

Table 6 shows the symbols for a few of the more common elements, along with the origins of the element's name. Perhaps the most intriguing is the metal cobalt, symbol Co, which is named after a goblin that miners invented. As noted earlier, in any two-letter symbol, the second letter is *always* lower case.

TABLE 6 Names, their origins and symbols for some elements.

Element name	Origin of name	Symbol	Relative mass
hydrogen	from the Greek: 'water forming'	H	1
helium	from the Greek, *Helios*: the Sun	He	4
boron	from the Arabic, *buraq*: borax	B	11
carbon	from the Latin: 'charcoal'	C	12
nitrogen	from '*gen*erated from nitre'	N	14
oxygen	from the Greek: 'acid forming'	O	16
sodium	from the English term, *soda*	Na	23
magnesium	from Magnesia, a district in Thessaly	Mg	24
aluminium	from the Latin, *alumen*: alum	Al	27
silicon	from the Latin, *silex*: flint	Si	28
phosphorus	from the Greek, *phosphoros*: light bringer	P	31
sulphur	from the Latin name for the element	S	32
chlorine	from the Greek, *chloros*: yellowish green	Cl	35
potassium	from the English term, *potash*	K	39
calcium	from the Latin, *calyx*: lime	Ca	40
iron	Anglo-Saxon name for the metal; the Romans called it ferrum	Fe	56
cobalt	from the German, *Kobold*: goblin or evil spirit	Co	59
zinc	from the German, *zink*	Zn	65
bromine	from the Greek, *bromos*: stench	Br	80
iodine	from the Greek, *iodes*: violet	I	127
gold	Anglo-Saxon name for the metal; the Romans called it aurum	Au	197

In Table 6 the elements are listed in order of increasing **relative mass.** As you have seen, the mass of individual atoms is very small. So, instead of expressing their mass in grams, it is easier to express them *relative to something that has a similar mass.* Here they are all expressed relative to the simplest atom—the hydrogen atom. Thus hydrogen is taken as having a mass of 1 (H = 1) and the other elements are expressed as multiples of the mass of the hydrogen atom. Look back to SAQ 1(c) on page 7 where you first met this idea.

By using symbols, elements can be represented much more conveniently and much more briefly. This method of using symbols can be extended to compounds. Let's look further into this idea using a very familiar compound: water. Recall what atoms there are in a water molecule.

□ What symbols would you use to represent the water molecule?

■ Since the water molecule has 2 hydrogen atoms and 1 oxygen atom, you might have written down HHO, HOH or OHH.

It is conventional to add up all the atoms of one type in a molecule, so it is written H_2O where the subscript 2 indicates that there are 2 hydrogen atoms and the absence of a subscript indicates that there is only 1 oxygen atom. Such a representation is known as a **chemical formula**. Arguably, we should write H_2O_1 but for convenience and simplicity the subscript 1 is always omitted. Unfortunately, there is no obvious rule to indicate which element should be written down first in a chemical formula. Do we write H_2O or OH_2? You know the answer, of course; we write H_2O. The reason is, essentially, a matter of convention: that's the way chemists do it. At first, you may find this system of writing formulae slightly awkward. Concentrate on remembering that the subscript refers to the symbol that *directly precedes it.* (The plural of 'formula' is 'formulas' or—better—'formulae', pronounced form-you-lee.)

□ Write down the chemical formulae for carbon dioxide and methane. You may need to look back in the text to remind yourself which atoms are present and in what proportions.

■ The chemical formula for carbon dioxide is CO_2 and for methane is CH_4.

> The chemical formula of a covalent compound shows the number of each type of atom in one molecule of the compound. It is written using the symbols for the elements.

We have examined the naming of elements, their symbols and the formulae of compounds. What about the names of compounds? As with elements, the everyday names of some compounds have their origins in history. One of the commonest and most important compounds is water, and words that *sound* like that have been used for this liquid for thousands of years. The old English term was 'waeter', in old Saxon 'watar', in old German 'wazzar' and ancient Greek 'hudor'. For common compounds these old names still linger on; water, ammonia, salt and alcohol are just some examples. But there are millions of different compounds—if they all had common names we would never be able to remember them. We need a simpler, more logical, naming-system that can be applied to any compound so that everyone can understand which compound is being talked about.

The scientific name reflects the elements found in the compound. Where a compound contains just two elements, the name of the second element is usually modified slightly so that it ends in the letters –ide, (pronounced as in 'side'). Thus, the compound HCl is hydrogen chlor*ide* not hydrogen chlor*ine*. Similarly, CO_2 is carbon dioxide not carbon dioxygen. The *di-* prefix indicates that there are two oxygen atoms and the *-ide* ending confirms that only two elements are involved in it.

Now try SAQs 8 to 11 using Tables 5 and 6 where necessary.

SAQ 8 Using chemical symbols and information in Section 2.4, draw structures for (a) a molecule of oxygen and (b) a molecule of nitrogen. Draw covalent bonds and not joined hooks.

SAQ 9 Which elements make up the following compounds? What is the ratio of the constituent atoms within each molecule?

(a) NH_3 (b) H_2S (c) PCl_5

SAQ 10 Write the chemical symbols for the elements that make up the following compounds:

(a) hydrogen bromide, (b) silicon dioxide, (c) boron trichloride ('tri' is the prefix for 3 atoms).

SAQ 11 Given that bromine, silicon and boron normally form 1, 4 and 3 covalent bonds respectively, and drawing on knowledge you already have about hydrogen and oxygen, write the chemical formulae of the compounds named in SAQ 10. (You *can* write down the formulae from the names alone by making use of 'di', 'tri' and 'ide'. If you answer the question by that method, use your understanding of covalent bonding to check the correctness of your answers.)

2.6 IONS

This Section returns to bonding—the way atoms are joined to each other. The focus here is on *ionic bonding* and the **ionic compounds** that contain such bonding. What is the main *difference* between the covalent compounds you met in Section 2.4 and ionic compounds? Are there any *similarities* between these two enormous families of chemical compounds?

To find an example of each, look back to Table 1 on page 2. Glucose is a covalent compound, and sodium chloride is an ionic compound. You meet glucose in solution in everyday life as it is the sugar of many sweet drinks (and is closely related to ordinary table sugar). You are certainly familiar with sodium chloride as this is the salt that is found in the kitchen! The formulae of both compounds tells us which atoms have combined together to make them. You can work this out for yourself in the ITQ.

□ The formula of glucose is $C_6H_{12}O_6$ and the formula of salt is NaCl. What elements are combined together to make glucose? What elements are combined together to make salt? Use Table 6 to help you if necessary.

■ The covalent compound, glucose, is formed from the elements carbon, hydrogen and oxygen. The ionic compound sodium chloride, is formed from the elements sodium and chlorine.

If you bought some glucose tablets from a chemists or an athletics shop and crushed them, you would have a fine white sweet powder—certainly *not* like the elements that form it: black carbon, gaseous hydrogen and gaseous oxygen.

Equally, sodium chloride is vastly different from the elements that combine together to make it. Sodium chloride is a white solid that is used on food. Yet chlorine is an enormously reactive green gas, deadly poisonous in concentrated form, that is an excellent disinfectant when dissolved in water, such as at the swimming baths. You probably won't have seen sodium as this silvery metal catches fire in air and almost explodes in water! Once again, the compound—an ionic compound in this case—is enormously different from its constituent elements.

If covalent and ionic compounds are similar in that they are unlike the elements that form them, in what key way do covalent and ionic compounds differ? The

answer is in the *nature of the bonding*. To understand something about ionic bonding, you need to recall what you learned in Section 2.3 about the internal structure of atoms.

□ What kind of charge does an electron carry? In what way is the overall electrical neutrality of atoms achieved?

■ Each electron carries one negative charge that we represent as −1. An atom is neutral because the number of protons (each of which bears a +1 charge) exactly equals the number of electrons.

Let's apply this to the elements that are in common salt. Table 4 lists the number of electrons (and hence protons) in five elements. Here, in Table 7, is the comparable information about sodium and chlorine.

TABLE 7 The numbers of electrons and protons in sodium and chlorine.

Element	Number of electrons	Number of protons
sodium	11	11
chlorine	17	17

How do these two elements bond together? Picture a sphere representing a sodium atom. The sphere isn't of course a solid sphere: it has a tiny central nucleus (with charge +11) and a cloud of electrons arranged in layers (of total charge −11). In many chemical reactions, an atom of sodium *very easily loses one electron* from the outer layer of this cloud of electrons. The loss of a single electron from a sodium atom makes it into a particle bearing a net *positive charge* of +1. This positive particle is termed an **ion.** By subtracting one electron from a sodium atom, a sodium ion is formed:

$$\underset{\text{sodium atom}}{Na} - \text{electron (of charge minus 1)} \rightarrow \underset{\text{sodium ion}}{Na^+}$$

This equation can be easily explained. The sodium atom is electrically neutral; it loses one electron with a charge of −1. By arithmetic, the particle that is left must have a charge of +1. Note that this is represented by the symbol for sodium with a small 'plus' sign written above the line (superscript). The following ITQ covers the same ground but looks at the change from atom to ion in overall terms.

□ Look back at sodium in Table 7. (a) What charge is in the nucleus after the electron is lost? (b) What total charge is there in the remaining set of electrons? (c) What, therefore, is the *net* charge on the ion as a whole?

■ (a) The protons are undisturbed; so the charge in the nucleus is still +11. (b) The electrons are one fewer than before; so their charge is −10. (c) The outcome of +11 and −10 is +1. So the *net* charge on the ion is +1.

Now picture a chlorine atom. This is electrically neutral: it has 17 electrons and 17 protons. In its reactions a chlorine atom *likes to gain one electron*. Following the same line of reasoning as before, adding one electron to this atom gives one extra negative charge. Thus a chlorine ion (usually called a chloride ion) is formed. Once again the ion is represented by the symbol for the element followed by the charge written as a superscript. Thus:

$$\underset{\text{chlorine atom}}{Cl} + \text{electron (of charge minus 1)} \rightarrow \underset{\text{chloride ion}}{Cl^-}$$

The fact that a sodium atom likes to lose an electron and a chlorine atom likes to gain an electron means that they have a great potential for satisfying 'each other's needs'. And this is what lies behind the violence of the reaction between shiny sodium metal and green poisonous chlorine gas. If you were to drop a lump of sodium into a jar of chlorine gas (behind armoured glass as the reaction is very violent and involves flames) *an electron transfer occurs*. The sodium loses an electron (so forming Na^+) and the chlorine gains one (so forming Cl^-). On the bottom of the gas jar, there would be a trace of white powder: the compound sodium chloride, common salt. The Na^+ ions and the Cl^- ions—

formed in the reaction—attract each other in a similar way that the comb attracted paper. The positive ions are strongly attracted to the negative ions.

☐ Suppose a billion sodium atoms lost one electron each to a billion chlorine atoms. (a) How many electrons move from Na atoms to Cl atoms? (b) How many sodium ions (Na^+) are formed? (c) How many chloride ions (Cl^-) are formed? (d) What is the net charge on the resulting sodium chloride? (e) How many molecules are formed?

■ (a) One billion; (b) one billion; (c) one billion; (d) none. The answer to (e) may surprise you: *NONE*!

The net charge on any ionic compound is always zero. The atoms, after all, start out neutral. All that happens is that some electrons move from one place to another. The total charge on the positive ions exactly equals the total charge on the negative ions.

The answer to (e) raises an important point. In ionic compounds such as salt, it is the attraction between the negatively charged chloride ions and the positively charged sodium ions which holds the substance together. This attraction *operates in all directions*, unlike the bonding in covalent compounds where the linking is directly between the atoms. Figure 16 shows this in a magnified piece of salt.

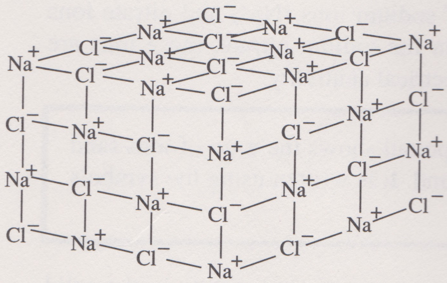


FIGURE 16 A magnified piece of salt. Here the solid lines represent the electrical attraction between every Na^+ and each of its neighbouring Cl^- ions. In fact this is a two-dimensional representation of a more complex three-dimensional structure.

A distinct *molecule* of sodium chloride *cannot* exist because each sodium ion is attracted to more than one chloride ion and vice versa. Thus drawing directional bonds between atoms as we did for the covalent molecules in Section 2.4 would be meaningless.

So far we have considered the Na^+ ion and the Cl^- ion which have lost and gained *one* electron respectively. Some atoms like to lose more than one electron or gain more than one electron. For example, atoms of the element calcium (another very reactive metal) always lose *two* electrons, so the calcium ion is always Ca^{++} normally written as Ca^{2+}. In this case the little '2+' when raised above the line (superscript) tells you that there are two plus charges on this ion.

Another example of a 'two electron change' is shown by atoms of the element oxygen. Recall that an oxygen atom forms two *covalent bonds* in some reactions (you saw this in Section 2.4 in H_2O and CO_2). However, in some other reactions it prefers to gain two electrons and thus forms ions. When this happens the ion formed is O^{2-}. This is called the oxide ion.

This preference for forming oxide ions is shown by oxygen in the many reactions where metals burn in oxygen. For example, calcium metal burns in oxygen to form the ionic compound *calcium oxide*. The formula for calcium oxide is CaO. This means that there is exactly one calcium ion (Ca^{2+}) to every oxide ion (O^{2-}) in a piece of calcium oxide. Thus the overall neutrality of the compound is maintained: 2+ and 2− = 0.

Note that the formula of an ionic compound gives the ratio between the two kinds of ions. By convention, we do *not* write charges in the formula. Thus we write NaCl and CaO and not Na^+Cl^- and Ca^{2+} O^{2-}.

What happens in an ionic compound when an ion containing two charges is combined with ions bearing only one charge? The 'golden rule' is that electrical neutrality must be maintained.

☐ Calcium chloride has the formula $CaCl_2$. What ions are in this compound and what is their ratio?

■ The subscript 2 in $CaCl_2$ means there are *two* Cl^- ions each of charge 1− i.e. 2− in total. The single Ca in $CaCl_2$ means *one* Ca^{2+} ion i.e. a total charge of 2+. In the compound as a whole the 2− charges and 2+ charges add up to 0. Thus neutrality is maintained.

TABLE 8 A summary of ions introduced in Section 2.6

Name of ion	Formula of ion
sodium ion	Na^{+}
potassium ion	K^{+}
calcium ion	Ca^{2+}
chloride ion	Cl^{-}
oxide ion	O^{2-}
nitrate ion	NO_3^{-}
sulphate ion	SO_4^{2-}

TABLE 9 Two common fertilizers.

Name of fertilizer	Formula
sodium nitrate	$NaNO_3$
potassium nitrate	KNO_3

So far in this Section we have described simple compounds containing only two types of element: one forms the positive ion and one forms the negative ion. There are, however, a number of ionic compounds that are more complex than this because one or both of the ions contain more than one element. One such ion is the nitrate ion, the principal villain in the story of water pollution by fertilizers.

The nitrate ion contains a cluster of atoms: one nitrogen atom and three oxygen atoms covalently bonded together *inside the nitrate ion*. However, the cluster of atoms as a whole bears just one negative charge just like a simple Cl^{-} ion. So the chemical formula for a nitrate ion is NO_3^{-}. Another ion that contains a cluster of atoms is the sulphate ion; this contains one atom of sulphur and four of oxygen. A summary of the ions you have met in this Section is given in Table 8, together with their formulae.

The negative nitrate ion pairs with a positive ion, of course. Sometimes this is a sodium ion (Na^{+}), alternatively it could be a potassium ion (K^{+}). Sodium nitrate and potassium nitrate are, in fact, two of the commonest fertilizers containing the nitrate ion. Table 9 lists these together with their chemical formulae. Sodium nitrate contains a vast number of sodium ions (Na^{+}) and nitrate ions (NO_3^{-}). As you can tell from the formula for sodium nitrate, these ions are present in equal numbers to give overall electrical neutrality.

> The chemical formulae of an ionic compound shows the ratio of ions (and atoms that form the ions) in that compound. It is written using the symbols for the elements.

The attraction of the positive and negative ions in sodium nitrate in the solid form, holds the compound together in a similar way to that shown for NaCl in Figure 16. When sodium nitrate is added to water, the water molecules interpose themselves between the two types of ions reducing the attraction between them and allowing them to separate. The result is that the solid sodium nitrate **dissolves** in water.

☐ What ions are present in potassium nitrate and in what ratio are they?

■ Potassium nitrate contains the potassium ion (K^{+}) and the nitrate ion (NO_3^{-}). They are in the ratio 1:1.

A final word about the names of ionic compounds may be helpful. In some ionic compounds (e.g. sodium chloride and calcium oxide), the name of the negative ion ends in '–ide'. As you know from the Section on covalent compounds, this simply denotes 'two elements in the compound'. However, in ionic compounds where the positive ion is balanced by a negative ion that *contains oxygen and another element* (such as in the ion NO_3^{-}), the ending usually changes to '–ate'. Thus the NO_3^{-} ion is called the nitr*ate* ion; the name tells you that the ion contains nitrogen and oxygen. Some general rules regarding the names of different substances are summarized in the Box.

> USEFUL ENDINGS IN CHEMICAL FORMULAE
>
> -ide This ending usually means that there are only two elements in a compound. The convention applies to both covalent and ionic compounds. In ionic compounds of this type, the name of the negative ion ends in -ide e.g. oxide, chloride.
>
> -ium This usually signifies a part of a compound that comes from an element that is a metal e.g. calcium, sodium. In ionic compounds this part is the positive ion.
>
> -ate This ending, applied only to ionic compounds, usually means that the negative ion itself consists of *two* elements, one of which is oxygen. Examples of such ions are the sulphate and nitrate ions.

SAQ 12 Name the following ionic compounds:

(a) CaO (b) KCl (c) Na_2SO_4 (d) MgO

SAQ 13 Write down the ions present in a solid sample of each compound listed in SAQ 12. In each case state what would be the ratio of positive ions to negative ions. You may need to refer to Table 8.

Check your answers to SAQs 12 and 13 at this point.

SAQ 14 Using your knowledge from the Modules so far (and your understanding of SAQs 12 and 13) write down the formulae of (a) calcium sulphate and (b) potassium sulphate.

SAQ 15 Magnesium sulphate is very soluble in water. What ions from magnesium sulphate would be present in the solution and in what ratio would they occur?

3 NITRATE AS A FERTILIZER

Having looked at the some of the basic types of bonding found in compounds, this Section goes on to look at the chemical nature of the various nitrates used in fertilizers. Before we proceed, let's look back at the terms listed in Tables 1 and 2.

□ On these Tables, tick off the entries which you have now met.

■ On our list in Table 1 we would tick the terms protein, sugar, salt, calcium, polyunsaturates and saturates; and in Table 2, the terms nitrate, nitrogen, proteins, and oxygen.

The Article refers to 'nitrate' fertilizer being put on the land, you now know this is not true! You simply cannot have a bucket of 'nitrate' to scatter on the crops.

□ Why is it impossible to have 'nitrate'?

■ Because nitrate ions are negative ions and cannot exist alone. Sufficient positive ions must be present to balance the negative ions.

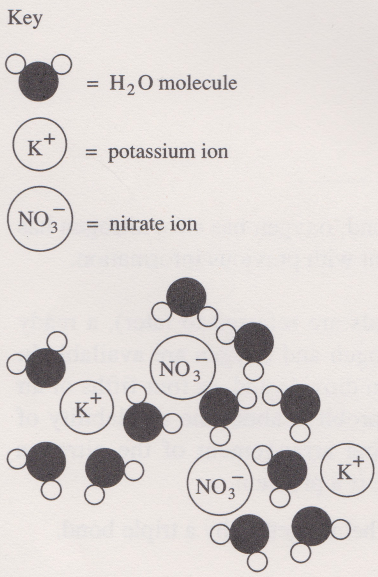


FIGURE 17 Potassium nitrate dissolved in water.

Depending on which chemicals the manufacturers of the fertilizer have chosen, the actual substance in the bucket could be potassium nitrate, sodium nitrate or a mixture. (There are other possibilities that are not discussed here.)

This kind of chemical sloppiness is almost universal in the way science is written about in the press. Even these Modules refer to 'nitrate' as an umbrella term for any ionic compound containing nitrate ions!

To return to fertilizers, look back at page 20 and note what was said there about how ionic substances dissolve. When it rains, ionic compounds such as sodium or potassium nitrate ($NaNO_3$ or KNO_3) dissolve in the water. Figure 17 shows how potassium ions and nitrate ions might spread themselves among (covalent) water molecules when a fertilizer containing KNO_3 dissolves.

The act of dissolving 'frees' the nitrate part from the sodium or potassium part, thus making the nitrate ion available to the roots of plants. From this solution in the soil, the nitrate ions are taken up into the plant where the nitrogen part of the nitrate ion is used to make important plant compounds such as proteins.

3.1 NITROGEN IN PLANTS AND ANIMALS

What is it then about the nitrate ion in fertilizer that makes it useful to apply to food crops and yet dangerous to young babies? To find out more we need to explore the role of nitrate ions—and of nitrogen atoms from the nitrate ions—in plants. We also need to consider what the nitrate ion does to animals.

Why do fertilizers contain nitrate? Why apply nitrate to the soil when, as was mentioned earlier, crops are surrounded by an abundance of these elements in the air? One of the main roles of nitrogen in plants (and indeed in animals) is that it is an important part of proteins. Proteins are important because they help to build cells. They are a group of large and complex molecules; there are many different kinds of proteins and all of them are formed from thousands of atoms linked together. Recall that the molecules are in the form of long chains: a section of such a chain is shown schematically in Figure 18. This is a more detailed version of the arrangement you met in Figure 6 and is as chemists write it using symbols for elements.

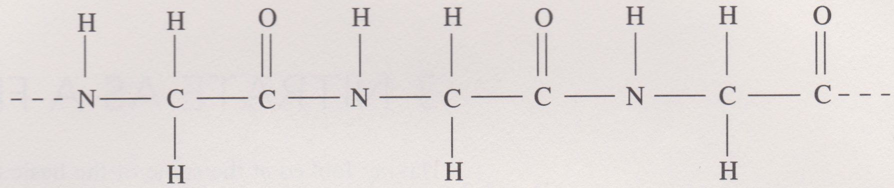


FIGURE 18 A chemist's representation of a protein chain showing the arrangement of the different elements.

□ By referring to Figure 18, write down in the Table below how many covalent bonds each type of atom forms. (As noted before, remember that this only represents part of the molecule, so the extreme atoms on the left and right of the structure are bonded to other, unseen, atoms). Is this consistent with our knowledge from earlier Sections?

Element	Number of chemical bonds
(a) hydrogen	
(b) oxygen	
(c) nitrogen	
(d) carbon	

■ Figure 18 shows that hydrogen has one bond, oxygen has two, nitrogen has three and carbon has four. This is consistent with previous information.

As proteins are essential for plant life (animals are referred to later), a ready supply of all four elements is essential. Hydrogen and oxygen are available in the form of water, carbon in the form of carbon dioxide and, as four fifths of air is nitrogen, at first sight there should be no problem about the availability of nitrogen. But let us look again at the bonding arrangement of the nitrogen molecules in air and it becomes plain that there *is* a problem.

In the N_2 molecule the two nitrogen atoms are held together by a triple bond.

$$N \equiv N$$

The way in which the nitrogen atoms are joined in this molecule results in a very stable structure and this triple bond is very difficult to break. *As a result of this plants are unable to utilize nitrogen from the air and need to obtain it from another source.*

This other source is the nitrate ion, naturally present in the soil. When dissolved in water, the nitrate ion is readily taken up by plant roots and once within plant cells it is converted to protein. It is perhaps ironic that plants are surrounded by air that contains one of the elements they need, but it is not in a form that they can use.

From the descriptions above, it is clear that plants need an adequate supply of nitrate. But where does this nitrate come from? How can a patch of land support plant growth, apparently for ever? In introducing the *nitrogen cycle*, Section 3.2 provides answers to these questions.

3.2 THE NITROGEN CYCLE

Plants grow perfectly well without the application of nitrate fertilizer. Think about areas of land that lie in remote regions: forested areas of Canada, grass on the mountains of the Lake District and Scotland and the rain forests of South America. Here, vegetation continues to grow year after year without fertilizer. In the beginning of Section 2, it was implied that sustained growth was related to the fact that when plants and animals die, the material of their bodies rots on the ground. Molecules containing nitrogen (especially proteins) in this organic material, are broken down into smaller molecules by bacteria in the soil. One of these molecules is ammonia, a compound of nitrogen and hydrogen.

□ How many bonds does nitrogen commonly form?

■ Three.

□ How many bonds does hydrogen form?

■ One bond.

□ Sketch an arrangement of the atoms in the ammonia molecule.

■ Figure 19 shows a chemist's representation of an ammonia molecule.

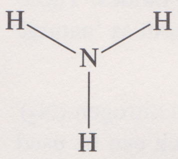


FIGURE 19 A chemist's representation of an ammonia molecule.

□ What is the chemical formula for ammonia?

■ NH_3

Ammonia is very easily converted to nitrates, again by soil bacteria, and this reformed nitrate can be used by plants for making protein. So there is a natural cycle of nitrogen (in its various chemical forms) that forms part of what is called the **nitrogen cycle**.

In addition to plants and bacteria, animals are also involved in this cycle. Animals cannot use nitrogen in the form of nitrates to make protein. They get their nitrogen-containing protein by eating plants (as cows and humans do) or by eating the animals that eat the plants (as lions and humans do). Thus animals directly or indirectly eat plants to obtain their supply of protein. The nitrogen in the protein of the animals is returned to the soil in their excrement or when they die.

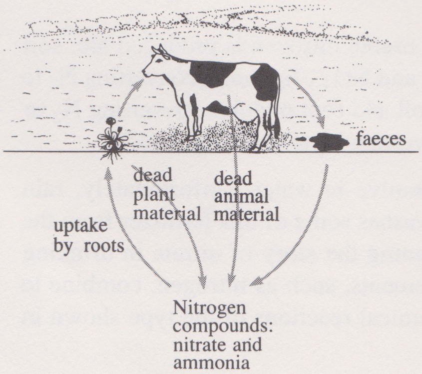


FIGURE 20 The basic nitrogen cycle. This shows the routes travelled by nitrogen compounds in soil, plants, animals and bacteria.

The part of the nitrogen cycle discussed so far is shown in Figure 20. But this is not the complete picture. In reality, there is an overall loss of usable nitrogen when animal and vegetable matter dies. Bacterial decay converts most of the nitrogen in this rotting matter to ammonia which is then converted to nitrate. But in areas where the soil is very cool and wet, the nitrates are converted back to nitrogen gas, N_2. These nitrogen molecules return to the air resulting in a loss of usable nitrogen from the land. We might expect there to be, in the long term, a steady decrease in the nitrates available in the soil. As this does not happen, there must be a return process by which the nitrogen in air becomes available to plants.

There are three main ways in which N_2 in the air is converted into nitrates, two of them natural and the other industrial. These are shown in Figure 21 and discussed below.

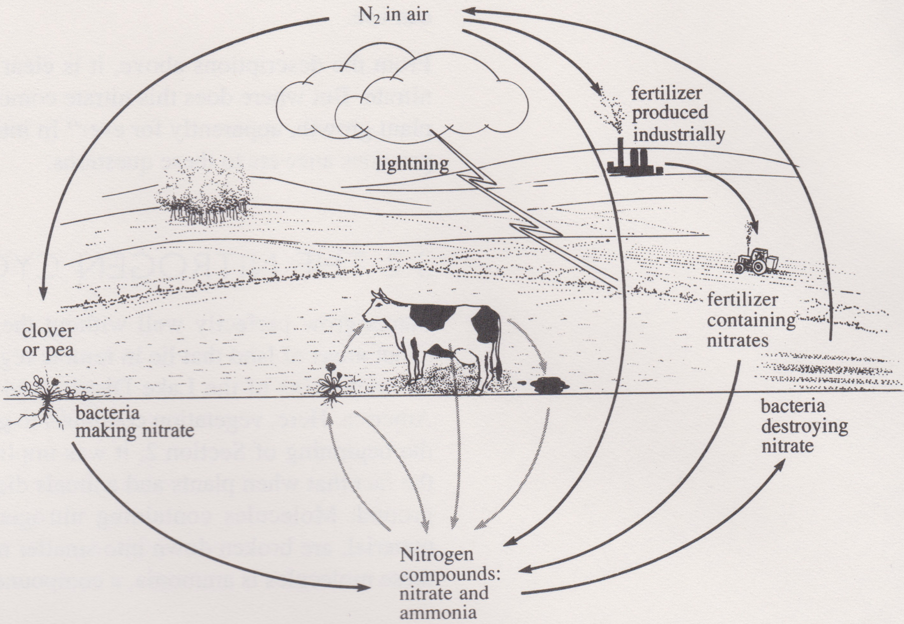


FIGURE 21 A more complete nitrogen cycle. Processes additional to those in Figure 20 are shown in black and are explained in the text.

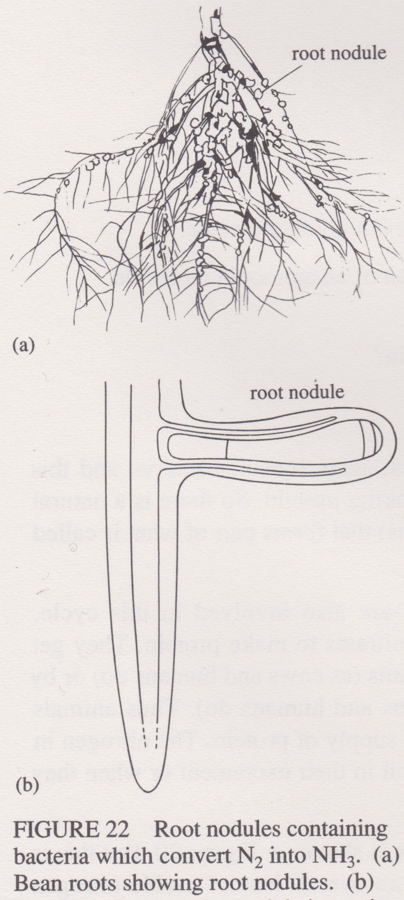


FIGURE 22 Root nodules containing bacteria which convert N_2 into NH_3. (a) Bean roots showing root nodules. (b) Diagram of a root plus nodule in section.

1 Nitrogen can be made to undergo chemical reactions if the triple bond in the N≡N molecule can be broken. Lightning discharges during thunderstorms can supply sufficient energy to do this. The 'solitary' nitrogen atoms formed (N instead of N_2) combine with oxygen in the air to form nitrogen oxides. These then dissolve in rainwater to form the nitrate ions which fall to earth as 'natural fertilizer'.

2 Some bacteria have the remarkable ability of taking gaseous nitrogen (N_2) from the atmosphere and converting it into ammonia, NH_3, which can be used by plants to make protein. Some of these particular bacteria live free in the soil; others live in the roots of peas, clover and related plants where they reside in swellings known as nodules. Figure 22 shows such root nodules.

3 Unfortunately, these natural ways of converting N_2 to usable forms of nitrogen are not sufficient to cope with the demand for soil nitrates brought about by intensive farming. The potential deficit is dealt with by the chemical industry and agriculture. N_2 from the air is converted to ammonia and this, in turn, is converted to various nitrates. These are applied directly to the soil as fertilizer.

In summary, the different routes by which usable nitrogen is produced are: soil bacteria converting dead organisms to NH_3 and NO_3^-, lightning converting N_2 to NO_3^- via nitrogen oxides, bacteria in the soil and root nodules converting N_2 to NH_3, and finally the chemical industry converting N_2 to fertilizer, NO_3^-.

You learnt above that fertilizers must dissolve in water. Unfortunately, rain water not only dissolves the fertilizer but washes some of this fertilizer from the fields into streams and rivers. Before pursuing the story of nitrate in drinking water further, we go on to look at how elements, such as nitrogen, combine to give compounds, such as ammonia, in chemical reactions of the type shown in the nitrogen cycle.

4 CHEMICAL REACTIONS

The nitrogen cycle illustrates how different elements can either exist on their own or can combine with other elements to make compounds. This Section builds on these ideas and looks at chemical reactions in more detail. It shows how chemical shorthand can be extended to describing chemical reactions. Because they are easier to understand, all the examples in this Section are reactions involving covalent molecules. Similar ideas apply, however, to reactions involving ionic compounds of the type you met in Section 2.6.

First consider some of the molecules described earlier: water, methane, carbon dioxide and ammonia.

□ What are the formulae for each of these four molecules?

■ H_2O, CH_4, CO_2 and NH_3, respectively.

Let's look at reactions involving the elements hydrogen, carbon and oxygen and the compounds methane and carbon dioxide.

Carbon reacts with hydrogen to form methane. To write such a reaction in terms of a **chemical equation**, the substances that undergo the reaction are put on the left and the substances that are produced in the reaction are put on the right. The **reactants** on the left are linked to the **products** on the right by the 'equals' sign.

The equation can be written as a word equation 'carbon and hydrogen make methane' or, using a little mathematical shorthand, it can be written as:

carbon + hydrogen = methane

Now, let's try using chemical shorthand to write the equation. Substituting symbols into the word equation gives:

carbon + hydrogen	=	methane
$C + H_2$	=	CH_4
reactants		product

The equation shows the reactants on the left being converted to the product on the right. But there is something wrong with this equation as written. You can see what is wrong by looking at Figure 23 where the reactants and products are drawn out in the fuller diagrammatic form used in Section 2.

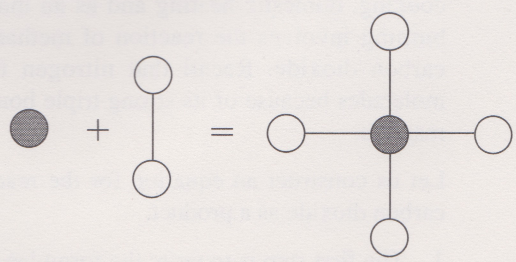


FIGURE 23 Diagrammatic representation of the unbalanced equation for the reaction between carbon and hydrogen to give methane.

Counting the numbers of atoms on each side of the equation shows that there are two hydrogen atoms more on the right compared with the left. Just as with mathematical equations, *chemical equations must balance.* The number of hydrogen atoms on both sides of the equation must be equal. It is not possible to change the right of the equation as the methane molecule exists as a group of four hydrogen atoms and one carbon atom all bonded together. Thus two *molecules* of hydrogen (each being a unit of two atoms) are needed to make a molecule of methane. The reaction is accurately expressed by:

$$C + H_2 + H_2 = CH_4$$

There are now the same number of each type of atom on both sides of the equation: the chemical equation is balanced.

A final tidying up to avoid repeating the hydrogen molecules on the left of the equation is to represent them by $2H_2$ rather than $H_2 + H_2$. So the balanced chemical equation becomes:

$$C + 2H_2 = CH_4$$

This is shown pictorially in Figure 24.

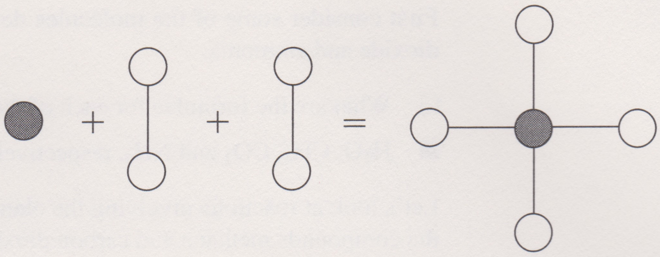


FIGURE 24 Representation of the balanced equation for the reaction between carbon and hydrogen to give methane.

Chemical equations show in a very concise way, not only which atoms and molecules are reacting together to form the products, but also how many of each sort of atom and molecule are involved. It is important to remember that the number before a molecule means the number of that particular molecule. For example $2H_2O$ means two molecules of water, giving a total of four hydrogen and two oxygen atoms.

> Chemical equations must balance; the number of atoms of each type of element on both sides of the equation must be equal.

GUIDED EXERCISE 1

The aim of this exercise is to build up a chemical equation which describes a chemical process.

Natural gas, which is largely made up of methane, is burned to provide heat for cooking, domestic heating and as an industrial power source. This process of burning involves the reaction of methane with oxygen in the air to produce carbon dioxide. Recall that nitrogen in air does not react with the other molecules because of its strong triple bond and it is not involved in the burning reaction.

Let us construct an equation for the reaction of methane with oxygen to give carbon dioxide as a product.

1 The first step is to write the formulae of the reactants on the left side and the product on the right:

$$CH_4 + O_2 = CO_2$$

2 Notice that the equation does not balance. The numbers of the carbon and the oxygen atoms are the same on each side, but there are four hydrogen atoms (as part of the methane molecule) on the left and none on the right. Without more information, it is *not* possible for us to balance this equation. There are two possibilities. Either hydrogen molecules are a product of the reaction and therefore must appear on the right of the equation, or the hydrogen in methane also reacts with oxygen.

To decide between these alternatives consider the following activity. If you hold a cold plate briefly over a gas flame, droplets of a colourless liquid form on the

plate. These droplets are water. So water is the other product of the reaction of methane with oxygen and so the incomplete equation becomes:

$$CH_4 + O_2 = CO_2 + H_2O$$

3 At this point all the products and reactants are featured, but the equation is still not balanced; the numbers of hydrogen and oxygen atoms are not the same on both sides of the equation. First deal with the hydrogen, four atoms on the left but just two on the right. To correct this, another water molecule is needed on the right:

$$CH_4 + O_2 = CO_2 + 2H_2O$$

□ Now deal with the oxygen.

■ To complete the equation another oxygen molecule is needed on the left to give the balanced chemical equation:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

Now the total numbers of atoms is the same on each side of the equation. Let us balance one more chemical equation before you have a go yourself.

GUIDED EXERCISE 2

This exercise involves writing a balanced chemical equation for the chemical reaction in which nitrogen, N_2, and hydrogen, H_2, react together to give ammonia NH_3. These are the only reactants and product involved.

1 The first step is to put the formulae of the reactants on the left and the product on the right:

$$N_2 + H_2 = NH_3$$

2 Now balance the number of atoms of nitrogen. With two atoms of nitrogen on the left, we need two ammonia molecules on the right. (Remember, N_2 means two atoms of nitrogen joined as a molecule.)

$$N_2 + H_2 = 2NH_3$$

3 The next problem is the number of hydrogen atoms with a total of six on the right (three in each of two ammonia molecules) and only two hydrogen atoms in the single hydrogen molecule on the left. To correct this, three hydrogen molecules are needed on the left (to give a total of six atoms).

$$N_2 + 3H_2 = 2NH_3$$

The result is a balanced chemical equation for a process in which one molecule of nitrogen reacts with three molecules of hydrogen to give two molecules of ammonia.

Balancing chemical equations is not easy but it does come with practice. Try practising by doing SAQ 16; before moving on to the next Section which looks at water.

SAQ 16 Balance the following equations. All reactants and products are shown. Some of them are covalent and others ionic, however, they are all treated in the same way.

(a) Magnesium is burned in oxygen to give magnesium oxide:

$$Mg + O_2 = MgO$$

(b) Carbon and chlorine react to form carbon tetrachloride:

$$C + Cl_2 = CCl_4$$

(c) Potassium oxide is formed by burning potassium in oxygen:

$$K + O_2 = K_2O$$

(d) Hydrogen reacts with chlorine gas to form hydrogen chloride:

$$H_2 + Cl_2 = HCl$$

5 WATER

Water is not only significant in the context of the Article, but it is one of the most important compounds in our lives. It plays a major role in our weather, our bodies are largely made up of water and our food has a large water content. In our bodies it serves many purposes, such as a transport medium (blood) and as a lubricating agent. Everyone in the UK takes water for granted but as a substance it has many interesting properties. The next Section looks at the different forms of water around us and its route in nature.

5.1 THE THREE FORMS OF WATER

Water can exist in three different forms, liquid, solid or gas. Liquid water is what you drink, swim in and wash with. It is found in oceans, rivers and lakes. The solid form of water is called ice on which people skate or put in drinks on hot days. It is found in large amounts at the north and south polar regions of the world. In fact most of the world's fresh water is in the form of ice in these regions. Water changes to ice when the temperature drops below 0 °C.

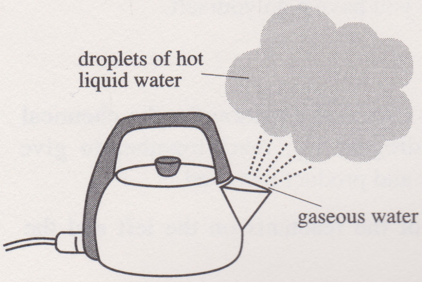


FIGURE 25 Water to water vapour and back to water.

When water is boiled by heating to 100 °C (boiling temperature) or allowed to **evaporate** at lower temperatures, it changes from a liquid to a gaseous form. The terms *water vapour* and *steam* are both terms used to describe this form. You may be surprised to learn that the gap between the spout and cloud in Figure 25 is true 'gaseous water' while the cloud itself is **condensed** droplets of water which is often also referred to as steam. You may have noticed a high flying jet plane with cloud trails behind the engines. These are in fact water droplets. Look closely and you may see a gap before the visible cloud trails form. The gap contains the true water vapour.

The molecule of water (H_2O) is the same whether the water is a liquid, solid or gas, so the change from gas to liquid or liquid to solid is not an example of a chemical reaction but involves a change of form due to a change of conditions. What does differ between the three forms is the closeness of the individual molecules to each other. Figure 26 shows a schematic illustration of the molecules in the three forms of water.

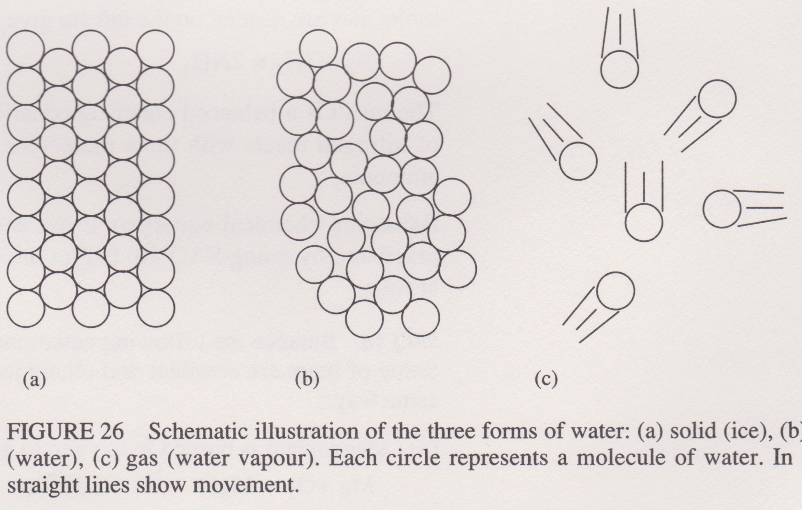


FIGURE 26 Schematic illustration of the three forms of water: (a) solid (ice), (b) liquid (water), (c) gas (water vapour). Each circle represents a molecule of water. In 'c' the straight lines show movement.

□ What do you think determines how close the molecules are?

■ The temperature determines the closeness of the molecules.

When it is very cold, water molecules pack together to form ice. With warmer temperatures, the water molecules spread apart to form liquid water. With more heat still, the water molecules move even further apart and become water vapour.

On Earth water is constantly being recycled. One of the most important events on Earth is the regular rainfall which brings plants and animals the constant supply of water they need to survive. But where does the rain come from and where does it go once it has fallen to the ground? The answers to these questions lie in an understanding of the water cycle (Figure 27).

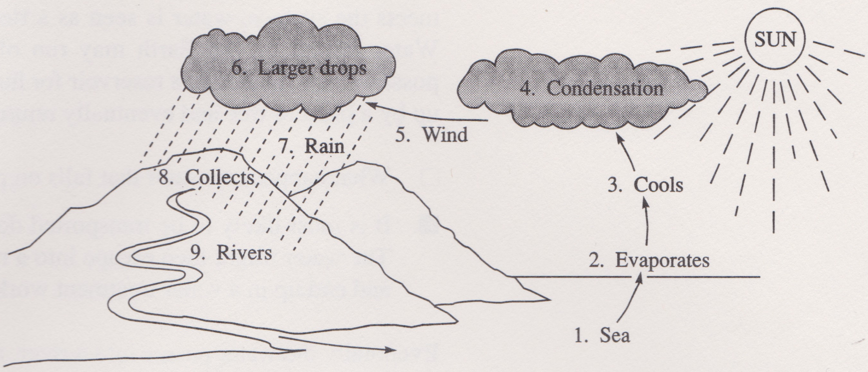


FIGURE 27 The water cycle. The main features of this cycle are as follows. (1) The seas and oceans are the biggest reservoir of water. (They are natural waters.) (2) The heat of the Sun causes this water to evaporate, as it does other natural waters. (3) The water vapour rises and cools. (4) It then condenses into tiny droplets which form clouds. (5) Prevailing winds carry the clouds along, and as they rise over land masses they cool further. (6) The small droplets form large drops. (7) The drops fall as rain. (8) The fallen rainwater feeds springs, streams, lakes and eventually rivers (again, natural waters). (9) The rivers flow into the sea and the cycle is complete, ready to begin all over again.

The water cycle describes the way in which water may be transported, and illustrates the dependence of this natural cycle on the interconversion between the vapour, liquid and solid forms of water.

We are going to follow the journey of one water molecule through the water cycle. Start in the ocean, where the water molecule is one among many being moved along in ocean currents. The molecule eventually finds itself at the surface of the ocean, where it is heated by sunlight. It may escape from the water surface, by evaporating into the air above; it then becomes part of an air stream moved by the winds. At this point it is invisible to the human eye, making up part of the air we breathe. This air always contains a proportion of water, although the proportion varies according to temperature. Warm air can carry more water than cold air, which partly explains why washing dries more quickly on warm days than cold ones. Sometimes, in the summer, we say that the atmosphere feels 'muggy'; this happens when the air already contains a high proportion of water, and so evaporation from our skin becomes slower and we start to feel sticky.

The water molecule is in an air stream that is moving towards land. When air meets a range of hills or mountains it is forced to rise in order to get over them. As the air rises, it starts to cool; you may have experienced the drop in temperature when climbing up a hill or mountain. Cool air cannot hold as much water as warm air, so at a certain height and temperature our molecule, along with other water molecules, condenses into very small droplets of airborne liquid water, which together form a cloud. You may sometimes see quite clearly that clouds have flat bases, which are all at the same level. Water molecules start to join together and droplets are formed which are kept within the cloud by the rising of heated air from the ground. The size of the droplet grows as more and more smaller droplets join together. Eventually the droplet grows too large to be held in the air any longer and starts to fall to Earth. Everyone, of course, is well acquainted with the effect of this process—rain.

□ What form would the water droplet take if it were to fall through the air at a temperature of below 0 °C?

■ It would probably be a hailstone or snowflake.

Having fallen to the ground, the water molecule may be subject to any one of a number of different fates. Some water will soak into the ground and percolate down to the level below which the rocks are permanently wet. This level is called the **water table**, and its depth below the Earth's surface fluctuates because of seasonal and annual variations in rainfall. A water molecule may remain here below the ground for hundreds of years. Where the water table meets the surface, water is seen as a flowing spring, as a stream, or as a lake. Water falling on the Earth may run off directly into a stream or river, and possibly be collected in a reservoir for human use. Alternatively, it may be taken up by a plant or tree and eventually return to the atmosphere.

□ What happens to water that falls on pavements and roads in towns?

■ It is most likely to be transported down gutters and drainpipes into a drain. The water might then escape into a river, or it might get mixed with sewage and end up in a water treatment works.

Eventually the water passes into a river, and then to the sea. From here the water molecule may move into an ocean and travel thousands of kilometres in deep ocean currents, perhaps through the mouths and gills of fish, until one day it once again evaporates from the surface into the air, and so the cycle continues.

5.2 FROM FERTILIZER INTO WATER

Recall from Section 4 that rain water contains nitrates. Some of this nitrate is carried down to the water table under the ground where it may be trapped for generations; some may run directly into a spring, stream or river. Water in agricultural areas, where the soil is laden with nitrate fertilizer, often has a much higher nitrate content. It is the higher levels of nitrates in our drinking water that was giving concern in the Article.

The chart in the Article (page 3) is just one way of showing how the concentration of nitrogen in ground water has changed over the years. There are a number of ways of expressing such changes: listing the data in a table, drawing a graph, or using a chart. The Figure in the Article is one of several types of **bar-chart**, commonly used in the media. It shows that the nitrogen level has increased during the period 1962 to 1992.

□ Why do you think that there has been an increase in nitrogen levels over the past thirty years or so?

■ The probable, but not proven, answer is that there has been an increasing amount of nitrogen in the form of nitrate fertilizer on the land with a consequential increased run-off into ground water.

The rate at which the nitrate moves through the soil into the water table depends on a number of factors including the amount of rainfall and the nature of the soil itself. Sometimes this process is very slow. This has obvious advantages in that it takes longer for the water table to become contaminated. On the other hand, even if the use of nitrates was banned, it would still take a long time for all the nitrates currently present in the soil to be washed out.

This problem has been recognized for some time and as a result the farming community is much more careful with the application of nitrate fertilizer. Nowadays, fertilizer tends to be spread on the land in smaller amounts and also at times of maximum uptake by crops. Increasing costs of fertilizer also make a more planned approach attractive. Unfortunately, it will take some years before the excess nitrate in ground water is reduced, but the next ten years should see a noticeable reduction in nitrate levels.

Having established how the nitrate gets into the watercourses, the next Section looks at the quality of water for drinking purposes.

5.3 WATER AND ITS IMPURITIES

For water to be of use for human consumption it must be of a certain quality. No natural water found on Earth is pure; any sample of water contains more than just water molecules. Some materials, such as sodium nitrate, are very **soluble** and dissolve in water in large quantities, whereas other materials are much less soluble. This is just as well otherwise rain would dissolve all the rocks and they would end up in the oceans!

Since it is not possible to produce drinking water that is absolutely pure, it is necessary to process water to make it acceptable for consumption. Very importantly, the water must not contain materials that are harmful. This requires the absence of both harmful bacteria and dissolved material that could prove dangerous. Water does not have to be absolutely pure to be drinkable, and indeed not only would it be an impossible task to make it so, but water is an important source of many of the metal ions (such as Ca^{2+}) we require in our diet. However, water must have levels of impurities that are below a danger threshold. How such thresholds are assessed can be a contentious matter, but in order to make comparisons, some measure of the amount of a particular substance dissolved in water is needed. In other words we need to know what **concentration** means. Concentration is the mass of a substance in a known volume of a liquid, for example, milligrams in a litre (mg l^{-1}).

As noted above, water from the tap is never pure in the sense that it contains only water molecules and no other chemicals. Even bottled mineral waters are not 100 percent water. What substances are dissolved in water? In what concentration is each present?

EXERCISE 3

If you use bottled mineral water, such as Perrier, have a look at the label and note down the contents. You will find that it contains a wide range of ions.

Table 10 gives the concentrations of some ions in various bottled mineral waters and two tap waters. Note that tap waters can vary substantially. You are already familiar with most of the ions listed in Table 10.

TABLE 10 Concentrations in mg l^{-1} of some important ions in various mineral waters and tap waters.

Ion	Volvic	Perrier	Strathallan	Ballygowan	Tap water Area 1	Tap water Area 2
calcium	9.9	145	30	117	130	50.0
magnesium	6.1	4	8	18	9.4	6.6
sodium	9.4	8	22	17	51	128
potassium	5.7	–	–	3	9.4	1.6
iron	<0.01	–	–	–	0.1	0.02
aluminium	<0.01	–	–	–	–	0.02
chloride	8.4	24	7	28	82	27.1
nitrate	6.3	17	0.3*	2*	26	17.6
sulphate	6.9	33	5.6	15	210	21.3

* as nitrogen < means 'less than' – too small to measure

□ What are the formulae for the following ions; calcium, sodium, potassium, chloride and nitrate?

■ In Section 2 you saw that calcium is Ca^{2+}, sodium is Na^+, potassium is K^+, chloride is Cl^- and nitrate is NO_3^-.

In order to be able to interpret Table 10 we need to clarify a few points. For example, what do the values in Table 10 mean? These are given as concentrations in mg l^{-1}.

☐ From Table 10, what is the concentration of chloride ion in Perrier water?

■ The Table shows the value of 24 mg l^{-1}. All this means is that in one litre of water there are 24 mg of dissolved chloride ions.

There are other values in the Table we need to look at, especially the concentration of nitrate ion. For Volvic water this is quite straightforward; there are 6.3 mg l^{-1}. But what about the value of nitrate in Ballygowan and Strathallan water? What does the 'as nitrogen' mean?

GUIDED EXERCISE 3

The aim of this Guided Exercise is to look at the relationship between the value of dissolved nitrate *expressed as nitrogen* and the value of dissolved nitrate *expressed as nitrate*. We know that there is nitrogen *in* nitrate from the formula, NO_3^-. But *how much* nitrogen is there in the nitrate ion? To answer this question we need to look back to Table 6 where we listed some elements and their masses relative to that of hydrogen. The relative mass of any compound or group of atoms is determined by adding together the individual relative masses of its constituent parts.

We can use relative mass to relate the mass of nitrate ion to the mass of nitrogen in that ion. The following steps show how.

1 Using the mass of the hydrogen atom as our unit of relative mass (i.e. H = 1), we work out the mass of the nitrate ion, NO_3^- relative to it. Do this by adding together the relative mass of one nitrogen atom and three oxygen atoms to get 14 + 16 + 16 + 16 = 62 units. (Remember that the mass of an electron is so small that it can be ignored.)

2 Of these 62 units how many are nitrogen? 14 parts of the 62 are nitrogen. So one part of nitrate contains 14/62 parts of nitrogen. Conversely, one part of nitrogen is contained in 62/14 parts of nitrate. So, in order to convert from mass of nitrogen in nitrate to nitrate itself multiply by 62/14. To convert mass of nitrate to mass of nitrogen multiply by 14/62.

☐ Convert the value for Ballygowan water from Table 10 from nitrogen to nitrate concentration?

■ The value for nitrogen in Ballygowan water is 2.0 mg l^{-1}. To convert this to nitrate multiply by 62/14. (Remember that nitrogen has a smaller mass than nitrate, so to convert to nitrate multiply by a fraction greater than one, that is 62/14 not 14/62.) So:

$$2.0 \text{ mg } l^{-1} \text{ nitrogen} = 2.0 \times \frac{62}{14} \text{ mg } l^{-1} \text{ nitrate}$$

$$= 8.9 \text{ mg } l^{-1} \text{ nitrate.}$$

This means that for water to have a nitrogen (in nitrate) concentration of 2.0 mg l^{-1} there must be 8.9 mg l^{-1} of dissolved nitrate. Note that the number of 8.9 mg l^{-1} is four to five times bigger than 2 mg l^{-1}! This observation is important for an understanding of the information in the Article as discussed in the next Section.

5.4 NITRATE POLLUTION

The first paragraph of the Article refers to the World Health Organization. Their maximum recommended level for *nitrogen* is 10 mg l^{-1} of water. A few lines later, there is the phrase, 'The allowed levels for *nitrate* in the EC are about five times higher.' Is it really the case that we accept a figure in the EC that is about

We can compare the two values by converting the EC value for nitrate (that is, about 5×10 mg l^{-1}) to a value for nitrogen.

To convert from nitrate to nitrogen we need to multiply by 14/62. Therefore, the nitrogen limit for the EC is:

$$50 \times \frac{14}{62} = 11.3 \text{ mg l}^{-1} \text{ nitrogen}$$

Once we take care to express nitrate content as mg l^{-1} nitrogen in both cases, the EC limit of 11.3 mg l^{-1} is very similar to the WHO limit of 10 mg l^{-1}. So, the alarm in the Article, 'The allowed level for nitrate in EC is about five times higher than the WHO level' was unfounded. The Article was misleading even though the values themselves were correct. Even when factual information is reported accurately, you need to be on your toes to avoid being influenced by writing that misinterprets the data.

This confusion between 'nitrate expressed as nitrate' and 'nitrate expressed as nitrogen', is not the only muddle! Turn now to the source of the water being measured. The Article confuses the difference between drinking water as it emerges from the tap, and the various natural water sources.

The chart in the Article is headed, 'Ground water impurities' and shows how levels of nitrogen in **ground water** have increased over the years. In fact the chart shows a rise in nitrogen levels for *one* natural source of water. Drinking water is often obtained by mixing different sources, sometimes from reservoirs and lakes, or from rivers, and sometimes from springs or by being pumped from underground wells. It is certainly true that impurities from one source of water can reach others but one does have to be clear just which sources are being examined.

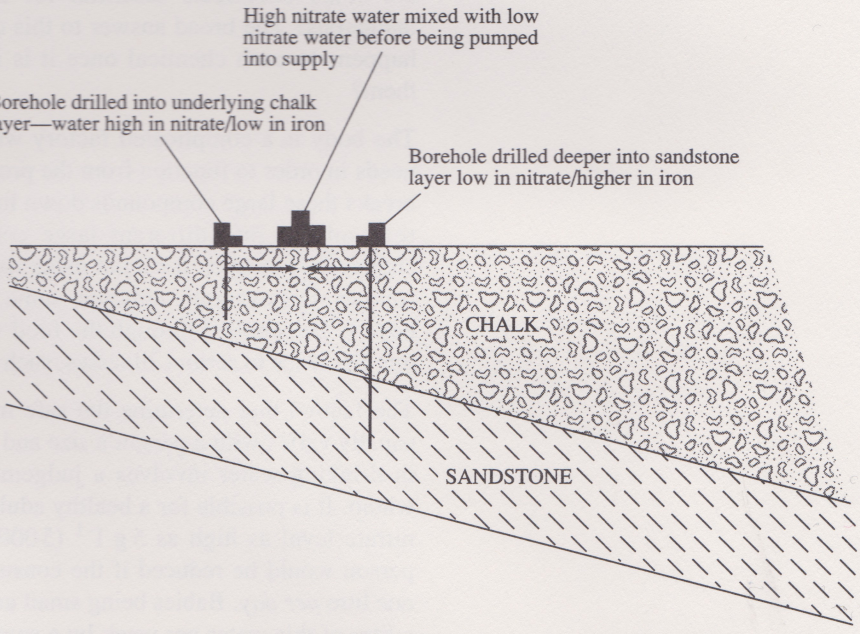


Figure 28 Tapping rocks at different depths to obtain water with different nitrate concentrations.

It is significant that within the Anglian Water region, which extends from the Humber to the Thames, over half the the drinking water is obtained from underground sources. In part of this region, namely Lincolnshire and West Norfolk, some sources produce water with high nitrate levels—up to 80 mg l^{-1}—but this water is *not used directly* for the drinking water supply. One way to reduce the nitrate concentration is to mix this water with water that has a very low nitrate concentration and fortunately there is a local source of such water. Water is obtained from two types of rock at different depths, as shown in Figure 28, and with different nitrate concentrations. These are then mixed. Unfortunately, the water low in nitrates is high in iron and this needs to be

removed before it can be piped to homes. However, the removal of iron ions is much easier to carry out than the removal of nitrate ions.

Thus the concentration for tap water is not necessarily as bad as for ground water though the trend and potential risk is worrying. The Article had a valid story to tell but overstated and overdramatized it and in the end gave a wrong impression. But why is there so much concern about the concentration of nitrates in drinking water; and why is it particularly dangerous to babies? The next Section addresses these questions.

SAQ 17 This question refers to the data in Table 10.

(a) Which bottled water has the highest concentration of sodium ions?

(b) Do any of these waters exceed the EC regulations for chloride concentration of $0.4\ g\ l^{-1}$?

SAQ 18 Convert the WHO allowed concentration of $10\ mg\ l^{-1}$ of nitrogen in nitrate into a value for nitrate concentration itself (to 2 significant figures).

6 FOOD AND DRINK REVISITED

You began these Modules by carrying out two exercises. The first was to draw up a list of chemicals found in food, each of which is an essential part of a healthy diet. The second exercise was to read an article about drinking water that suggested there was a problem of contamination with harmful chemicals. Why are some chemicals essential for human survival and others potentially dangerous? The broad answer to this question lies in an understanding of what happens to each chemical once it is in the body. How does the body handle them?

The body is a complicated factory which can make many of the chemicals it needs in order to function from the protein, carbohydrates and fats in our diet. It breaks these large compounds down into smaller compounds which can then be reassembled into different large compounds required by the body. Some chemicals, however, it cannot make itself and these must be taken in from other sources. For example, although some vitamins can be made in the body, most have to be supplied through the food we eat. Absence of these chemicals from our diet leads to serious illnesses, such as scurvy and rickets.

The factors that determine the safe maximum daily amount of any substance usually varies with a person's size and age. The crux of the problem with nitrate in drinking water involves a judgement of what is a safe level and safe for whom. It is possible for a healthy adult to drink a litre of water *per week* with a nitrate level as high as $5\ g\ l^{-1}$ ($5\,000\ mg\ l^{-1}$), but the life expectancy of that person would be reduced if the consumption of such water were at the rate of one litre *per day*. Babies being small are vulnerable. The drinking of one tenth of a litre of this water per week by a small baby could possibly be lethal. Why are nitrates, beyond a certain level of intake, dangerous?

To answer this question, we need to consider how the human body uses and transports oxygen. Oxygen from the air is taken in by the lungs and used by the cells throughout the entire body. Therefore it has to be transported around the body and this is one of the important roles of the blood stream.

Blood is a complex fluid containing dissolved materials and also different types of cells. One particular type is responsible for transporting oxygen throughout the body. In these cells there is a large molecule known as haemoglobin (pronounced hee-mo-globe-in) in which an iron atom is linked to carbon and nitrogen atoms. This is why iron is an important component of the diet (Table 1); most of it ends up in haemoglobin.

The important feature of this molecule is that the iron atom is able to bond to an oxygen molecule. When these enter the blood stream from the air taken into the lungs, they attach themselves to the iron atoms of the haemoglobin molecules and are carried to the parts of the body where they are needed for survival of cells. The bond between the iron atom and the oxygen molecule is not particularly strong, so haemoglobin is able to give up the oxygen where it is needed.

Unfortunately, this willingness to give up oxygen can lead to problems when drinking water has nitrate dissolved in it. The problem known as 'blue baby syndrome', occurs when infants less than about one year old consume too much nitrate. The nitrate is converted in their stomachs into a form that interacts with the iron in the haemoglobin so that the haemoglobin is no longer 'free' to combine with oxygen. This effectively prevents the transport of oxygen to the cells, so it is possible for the baby to suffocate—even though there is plenty of oxygen in the lungs.

The colour of haemoglobin that carries oxygen is bright red, but when starved of oxygen the molecule assumes a purple-blue colouration. It is the change of colour of the blood that is apparent in 'blue baby syndrome'. The danger of nitrate to very young babies, is due to the fact that the chemical make-up of their stomachs at this age, seems to encourage the conversion of nitrate to a form that readily combines with haemoglobin. Levels of nitrate that are not high enough to be lethal can, nevertheless, result in a baby suffering an oxygen shortage.

7 OVERVIEW

SUMMARY

These are the concepts that you have learned about in these Modules:

- Elements are substances that consist of only one type of atom.
- Each type of atom contains a characteristic number of protons in a central nucleus and an equal number of electrons in layers surrounding the nucleus.
- Compounds contain two or more elements combined together.
- There are two kinds of bonds between atoms: covalent and ionic.
- Molecules are the smallest units in which elements and/or compounds can exist covalently bonded together.
- Ions are formed by atoms or groups of atoms gaining or losing electrons.
- Chemical formulae describe the number of atoms present in elements, ions and compounds.
- Relative mass is a measure of the mass of an atom, ion or compound relative to the mass of a reference atom.
- Chemical equations describe, using chemical formulae, the reactants and products in a balanced chemical reaction.
- The nitrogen cycle describes the way in which nitrogen circulates between the air, the soil, plants and animals.
- The water cycle describes how water is continuously re-cycled from sea, into the atmosphere, to land via rain, and so back to the sea via rivers.
- Water exists in three forms: ice, water and vapour.
- Concentration is the mass of a substance dissolved in a given volume (usually 1 litre) of a liquid.

SKILLS

Now you have completed these Modules you should be able to:

- read data presented in tables
- interpret and write chemical formulae
- read, construct and balance simple chemical equations
- calculate the mass of a compound, ion or molecule in comparison with the mass of hydrogen
- calculate the concentrations of chemical substances dissolved in water
- assess scientific writing in a more critical way.

APPENDIX 1: EXPLANATION OF TERMS USED

As you progress through the Modules you will meet some of these terms and concepts again and learn more about them.

ATOMS Atoms are very small, around 10^{-10}m in diameter. Each element of the one hundred different elements that exist have different atoms. Atoms bond to each other covalently forming molecules, or ionically to form ionic compounds. Atoms have an internal structure involving electrons, protons (and neutrons).

ATOMIC NUCLEUS The nucleus of an atom. Often referred to as simply the 'nucleus' where the meaning is clear from the context.

BAR-CHART A graph which uses bars to represent quantities of one or more items.

BONDS The links between atoms which are of two types: covalent and ionic.

CELLS The basic units from which animals and plants are built.

CELL NUCLEUS A structure inside most animal and plant cells. Often referred to as simply the 'nucleus' where the meaning is clear from the context.

CHEMICALS A very unspecific term, loosely used. All chemical compounds are chemicals, as are all elements. Although we might not think of everyday substances (such as water, a gold ring or the mixture of gases we call air) as chemicals, they in fact are.

COMPOUND A substance formed from two or more elements by the process of a chemical reaction. Compounds are generally covalent or ionic.

CHEMICAL EQUATION This describes, by means of chemical formulae, the reactants and products in a chemical reaction. A chemical equation must balance in terms of the type and number of atoms involved.

CHEMICAL FORMULA A representation of the number of each type of atom which make up one molecule of a covalent substance *or* a representation of the ratio of ions (and of atoms that formed the ions) in ionic substances. They are written using the symbols for elements.

CONCENTRATION The mass of a substance dissolved in a given volume (usually 1 litre) of a liquid. The units of concentration are mass per unit volume, for example, grams per litre.

CONDENSATION The process by which a gas changes to a liquid.

COVALENT BONDING The kind of bonding in molecules of compounds or of elements. The formation of covalent compounds depends on the sharing of electrons between atoms that bond together.

COVALENT COMPOUNDS Compounds containing only covalent bonds.

DISSOLVE The process by which a solid goes into solution in a solvent. The solvent is frequently water. When the substance is ionic the ions separate and spread themselves among the water molecules.

DOUBLE BONDS This term means double *covalent bonds*. One example is the carbon to oxygen double bonds in proteins. Carbon to carbon double bonds occur in *unsaturated compounds*.

ELECTRONS Small negatively charged particles with little mass that form part of the internal structure of atoms. Electrons are lost or gained in ionic bonding or shared in covalent bonding.

ELEMENT A substance consisting of only one type of atom. There are about one hundred in existence. Some elements exist in nature as covalent molecules often of two atoms joined together e.g. H_2. A few exist as single atoms e.g. helium. (Some elements exist as metals, these are not discussed in *Into Science*.)

EQUATION See 'chemical equation'.

EVAPORATION A process by which a liquid is converted to a vapour or gas.

GROUND WATER Water that has been absorbed into the ground and held by porous materials such as chalk or sandstone.

IONIC BONDING The kind of bonding that occurs in ionic compounds. Such compounds possess positively and negatively charged atoms or groups of atoms that are called ions which attract each other thus forming an extended arrangement of mutually attracting ions instead of a molecule.

IONIC COMPOUNDS Compounds containing ionic bonds.

IONS Formed from atoms by gaining one or more electrons (negative ions) or losing one or more electrons (positive ions).

MOLECULE This is the smallest particle of an element or covalent compound that can normally exist independently. Molecules of elements such as hydrogen and oxygen can be split into atoms but left alone would reform H_2 and O_2.

NITROGEN CYCLE This describes the routes taken by the compounds of nitrogen (and by nitrogen gas) in their passage from soil and air into living organisms and then back to soil and air.

NUCLEUS See either cell nucleus or atomic nucleus.

PRODUCTS The chemical compounds, elements or ions present at the end of a chemical reaction.

PROTEIN A compound containing carbon, hydrogen, oxygen and nitrogen. Proteins are found in all living materials.

PROTON The positively charged component(s) of the nucleus of an element. Each element has atoms with a unique number of protons. The number ranges from 1 to about 100.

REACTANTS The chemical compounds, elements or ions present at the beginning of a chemical reaction.

RELATIVE MASS This is a measure of the mass of an atom or compound relative to the mass of a reference atom. In *Into Science* we have taken the reference mass as that of hydrogen with a mass of one unit.

SINGLE BONDS This term means single *covalent* bonds. An example is the bond between an H and and an O in H_2O. Carbon to carbon single bonds occur in *saturated compounds.*

SOLUBILITY The capacity a substance has for dissolving.

SYMBOL The letter (or pair of letters) used as the chemical shorthand for each element. Where two letters are used, the first is always a capital and the second is always lower case. Symbols stand for atoms in chemical formulae and in equations.

WATER TABLE The level in the ground below which the rocks are saturated with water.

APPENDIX 2

Figure 29 shows our labelled drawing of a carbon atom. You were asked to draw this in the ITQ on page 10. It is based on Figure 7.

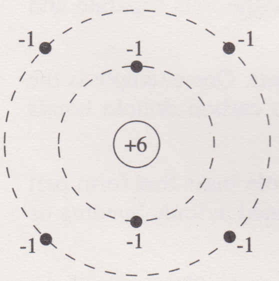


FIGURE 29 Chemists' simple representation of the carbon atom. The dots represent electrons in layers around the central nucleus shown by a white circle. There is a charge of +6 in the nucleus and 6 electrons each with a charge of -1.

SAQ ANSWERS AND COMMENTS

SAQ 1

(a) As 6×10^{23} atoms of H have a mass of 1g, it follows that one atom has a mass of:

$$1g \div 6 \times 10^{23} \text{ or } \frac{1}{6 \times 10^{23}}$$

So, the mass of one atom of hydrogen is 1.67×10^{-24} g.

(b) As 6×10^{23} atoms of C have a mass of 12 g, it follows that one atom has a mass of:

$$12\text{ g} \div 6 \times 10^{23} \text{ or } \frac{12}{6 \times 10^{23}}$$

Thus, the mass of one carbon atom is 2.00×10^{-23} g.

(c) To 2 sig figs, an atom of carbon is 12 times as heavy as an atom of hydrogen. This is obtained by dividing 2.00×10^{-23} g by 1.67×10^{-24} g. This idea of 'the mass of a carbon atom relative to the mass of a hydrogen atom' is important in chemistry.

SAQ 2 Hydrogen, nitrogen and carbon are elements (because they each consist of only one type of atom); water and protein are compounds.

SAQ 3 In fact, two answers are equally correct. Either fill in the blanks with elements/ hydrogen/ compound OR with atoms/ hydrogen/ compound.

SAQ 4

(a) Oxygen is an element (b) nitrogen is an element (c) carbon dioxide is a compound.

SAQ 5 A gold atom has 79 electrons. Atoms of gold, like atoms of all other elements, are electrically neutral. The charge carried by a proton is +1 so the charge on the nucleus of a gold atom is +79. To balance this there must be 79 electrons each with a charge of -1.

SAQ 6 There are 7 protons in the nucleus of a nitrogen atom. This can be deduced as follows: as there are 7 electrons surrounding the nucleus in a nitrogen atom, the total negative charge is -7. Since the atom is electrically neutral, and as the charge on a proton is +1, there must be 7 protons altogether.

By similar reasoning, the numbers of protons per atomic nucleus in each of the following elements is as follows:

oxygen 8, argon 18, neon 10,

helium 2, krypton 36, xenon 54.

Note, for interest, there is nearly 1% of argon in the air we breathe.

SAQ 7 (a) and (b) are likely to exist and in fact *do* exist as covalent compounds. (c) is most unlikely as carbon forms four and not five covalent bonds. The compound CCl_5 does not, in fact, exist.

SAQ 8 O=O and N≡N. You may have gone through the stage of drawing linked hooks to get to these molecular structures showing double and triple covalent bonds respectively.

SAQ 9

(a) Nitrogen and hydrogen, the atoms are in the ratio of 1:3 within the molecule of NH_3 (called ammonia)

(b) Hydrogen and sulphur, the atoms are in the ratio of 2:1 respectively within the molecule of H_2S (called hydrogen sulphide). (c) Phosphorus and chlorine, the atoms are in the ratio of 1:5 within the molecule of PCl_5 (called phosphorus pentachloride: note 'penta' means five).

SAQ 10 Hydrogen = H, bromine = Br, silicon = Si, oxygen = O, boron = B, chlorine = Cl

SAQ 11 Hydrogen bromide = HBr
silicon dioxide = SiO_2, boron trichloride = BCl_3

(This ties in with their names, with the meaning of 'di' and 'tri' and also with the idea of 'preferred' number of covalent bonds.)

SAQ 12

(a) Calcium oxide (b) potassium chloride
(c) sodium sulphate (d) magnesium oxide.

SAQ 13

(a) Ca^{2+} and O^{2-} in the ratio 1:1

(b) K^+ and Cl^- in the ratio 1:1

(c) Na^+ and SO_4^{2-} in the ratio 2:1

(d) Mg^{2+} and O^{2-} in the ratio 1:1

Although Mg^{2+} is not in Table 8 you can deduce it from the formula MgO knowing that oxide ion is O^{2-}

SAQ 14

(a) The formula for calcium sulphate is $CaSO_4$ (one Ca^{2+} ion and one SO_4^{2-} ion)

(b) The formula for potassium sulphate is K_2SO_4 (two K^+ ions and one SO_4^{2-} ion)

SAQ 15 Mg^{2+} and SO_4^{2-} in a ratio of 1:1. You know from SAQ 13 part (d) that the ions of magnesium are Mg^{2+}. Hence, magnesium sulphate is $MgSO_4$; the charge of 2+ on the magnesium ion balances the charge of 2– on the sulphate ion (SO_4^{2-}).

SAQ 16 Remember that the numbers of atoms of each element must be the same on both sides of the equation. So:

(a) $2Mg + O_2 = 2MgO$

(b) $C + 2Cl_2 = CCl_4$

(c) $4K + O_2 = 2K_2O$

(d) $H_2 + Cl_2 = 2HCl$

SAQ 17

(a) Strathallan (22 mg l^{-1})

(b) At first sight it may seem as if they all do. However, the EC limit is given in g l^{-1}, if we convert this to mg l^{-1} (400 mg l^{-1}) we can see that they are all within EC limits.

SAQ 18 To convert the value of nitrogen of 10 mg l^{-1} to the value of nitrate, multiply by 62/14 (see page 32 for explanation).

$$10 \times \frac{62}{14} = 44 \text{ mg } l^{-1} \text{ of nitrate.}$$

The value for nitrate is 4 to 5 times bigger than the value for nitrogen.